3D atlas of human embryology

New insights in human development

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“We do not learn best by memorizing facts about the subject. Because reality is communal, we learn best by interacting with it. ... In a wide variety of ways, good teachers bring students into living communion with the subjects they teach.”

Parker J Palmer, 1983
Abstract

Knowledge of embryonic development is essential to understand the positioning of organs in the human body. Unfortunately, (bio)medical students struggle to grasp the intricate morphogenesis of the developing human body by studying textbooks since texts use static, two-dimensional (2D) schematics. To facilitate embryology education on an understandable and scientific level, a 3D Atlas of Human Embryology was created and published in Science in 2016, encompassing 14 interactive 3D-PDFs of various stages of human embryonic development (freely available from http://www.3datlasofhumanembryology.com). To find out whether this 3D atlas has a significant added educational value in the (bio)medical curriculum, we examined by means of a questionnaire and outcomes in written exams whether the use of this interactive 3D atlas to accompany embryology lectures improves the students learning experience. Our results show that although its use did not significantly improve the students test scores, the 3D atlas facilitates students’ learning experience as a resource to accompany embryology lectures. Students appreciated the use of the 3D atlas in practical classes and liked the interactive aspect of the 3D atlas. Interestingly, the students also highly appreciated the physical 2D hand-painted embryological models that were used in addition to the digital 3D atlas during practical classes. The 3D atlas has proven to be a valuable resource in addition to the existing resources to teach the intricate developmental processes of human embryology, especially in a blended learning curriculum.

Introduction

Teaching anatomy and embryology is an important part of the (bio)medical curriculum. Knowledge of embryonic development is crucial to grasp the intricate topographic relations of organs in the human body and to understand the etiology of congenital malformations. In most embryology courses at medical schools students can only use textbooks to study embryology in addition to the presented lectures. Unfortunately, students find it hard to gain insight into the morphogenesis of the developing human body from textbooks, since books use flat images of cross sections and static schematic images. This often frustrates students who have to learn details of three-dimensional (3D) embryonic growth processes. Also, in the absence of qualified embryologists, embryology education is at risk of being eliminated from the (bio)medical curriculum, with consequences for students' basic knowledge of the human body plan.

The opportunity to process visual information is important to understand embryonic development (Evans et al., 2011). Most educators use different approaches and modalities to put this knowledge into a format that is the most effective for students. Carmichael and Pawlina (2000) demonstrated that students considered animated PowerPoint (PPT™, Microsoft ®) presentations during anatomy lectures to be a valuable addition to the course. Other research showed that in addition to classroom lectures, online embryology screencasts were accessed heavily by medical students throughout the course, which emphasizes the need for visual computer-aided learning in embryology (Evans et al., 2011; Nieder and Nagy, 2002). Exam scores showed that the screencasts had a positive effect on students’ outcome. This type of blended learning in embryology, in which traditional lectures are combined with online teaching resources, enables students to choose customized learning experiences to achieve their individual learning goals (Graham, 2013).
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In 2015 S. Seppings of the Swansea University, Swansea, UK posted a clay animation of heart development online, offering students a new and creative way of looking at embryonic development (https://www.youtube.com/watch?v=RpZHwtkFUM4). The ability to interact with a 3D model might be of added value since the process of embryonic development needs to be envisioned from different viewpoints to thoroughly understand the 3D spatial and temporal developmental processes. Marsh et al. (2008) introduced a module with simple 3D animated models of early embryology, and found that the students appreciated the way those models presented developmental processes that could not be presented on paper. This indicated that student felt a need for an interactive 3D representation of embryonic development.

To facilitate embryology education on an understandable, yet scientific level, a free 3D Atlas of Human Embryology (http://www.3datlasofhumanembryology.com), encompassing 14 interactive 3D-PDFs of various stages of the first two months of human development (Fig. 1; De Bakker et al., 2016), was created. These interactive 3D models provide detailed information on the development of up to 150 organs and structures per embryo that can be interactively viewed from all sides. Furthermore, the students can manipulate the models in virtual 3D space, which facilitates active exploration of the embryos in the classroom or elsewhere. Compared with textbooks, which present the development and topology of each organ system in separate chapters, these 3D models allow better appreciation of the topographical relations of various organs, a learning approach which proved to result in better outcomes for medical students (Ferguson et al., 2002; Ward, 2011a,b).

To find out whether the 3D Atlas of Human Embryology has a significant added educational value in our curriculum for (bio)medical students, we examined whether the use of the interactive 3D atlas to accompany embryology sessions improved the students’ learning experience. Therefore, we analyzed qualitative and quantitative feedback from a student questionnaire as well as students’ outcomes in written exams.

Methods

Participants and setting

This study was conducted at the Academic Medical Center, University of Amsterdam, Amsterdam, the Netherlands, during the 2016-2017 academic year with one cohort of first year undergraduate biomedical science and biology students. Their average age was 19 years with a range between 17 and 23 years.

The four week embryology course comprised of a series of 14 classroom lectures of 45 minutes each, organized in three main subjects: embryo morphology (six lectures), basic developmental concepts (four lectures) and development of the heart (four lectures). These classroom lectures are accompanied by three practical classes of two and a half hours each in the second, third and fourth week of the course. Prior to the practical classes the students were asked to complete E-learning modules as preparation for the assignments during classes. During these classes students worked on assignments in groups of about five students, under supervision of embryologists (Fig. 2). For several assignments students used plastic hand-painted physical models of human and chicken embryos (http://www.somso.de), which were also used in previous years. In 2016-2017 the assignments were updated in such a way that the students had to use the 3D Atlas of Human Embryology (De Bakker et al., 2016) next to the physical models. The course concluded with a written exam at the end of the fourth week.
Fig. 1. An example of the interface of a 3D-PDF from the 3D Atlas of Human Embryology. The presented model is a stage 20 (51-53 days of development) human embryo, specimen number 462 from the Carnegie collection of the Human Developmental Anatomy Center at the National Museum of Health and Medicine in Silver Spring, MD, USA. Eight educational predefined views can be selected on the bottom of the 3D-PDF. On the left all organ systems and single selected structures can be separately turned on or off or be made transparent. All 14 3D-PDFs covering the first eight weeks of embryonic development are freely available from http://www.3datlasofhumanembryology.com. Adobe Reader® X or higher (http://www.adobe.com/downloads/) is needed to properly open and view the 3D-PDFs.

Table 1. Number of respondents and demographics for the students cohort

<table>
<thead>
<tr>
<th>Type of students</th>
<th>Number of students</th>
<th>Number of respondents (%)</th>
<th>Sex</th>
<th>Mean Age (y)</th>
<th>Number of students recommending practical classes in current form</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>New students</td>
<td>174</td>
<td>77 (44%)</td>
<td>23</td>
<td>54</td>
<td>60</td>
</tr>
<tr>
<td>Repeaters</td>
<td>33</td>
<td>14 (43%)</td>
<td>7</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Total 2016-2017 cohort</td>
<td>207</td>
<td>91 (44%)</td>
<td>30</td>
<td>61</td>
<td>68</td>
</tr>
</tbody>
</table>
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**Study design**

At the end of the second practical class the students were asked to fill in a questionnaire to gather feedback on the practical classes and specifically the 3D atlas. Survey participation was voluntary and anonymous, and there were no rewards offered for completing the survey. The first three questions addressed age, gender and whether the student was a repeater for this course due to an insufficient grade the previous year. Then, students were asked to indicate on a scale from 1 to 5 (i.e. “Strongly negative”, “Negative”, “neutral”, “Positive”, “Strongly positive”) their opinion on the practical classes and the use of the 3D atlas in these classes. In addition, students were asked a number of open questions concerning their opinion on the interface of the 3D atlas and their experience with using the atlas during the assignments. Furthermore, students were asked to give feedback on the practical classes and the embryology teachers.

At the end of the course, the students’ knowledge on the studied topics was tested with a written exam encompassing 40 multiple choice questions (one point for each correct answer). In terms of content and difficulty this exam was similar to the exam in the previous year.

![Fig. 2. Atmosphere impression during a practical class.](image) Students work on assignments in groups of about five students, under supervision of embryologists (top). Note the laptop with the 3D atlas (middle) and the physical hand-painted models on the table (bottom). University of Amsterdam FNWI Communication, with permission.
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Statistical analysis
The questionnaire was administered to one cohort of biomedical and biology students (N = 207) and responses on the questionnaire were analyzed for statistical significance. Pearson Chi-Square tests were conducted to determine statistical differences between new students and repeaters for categorical data (whether they would recommend the practical classes in the current form for future practical classes). Written exam results (scale from 0 to 40), of cohort 2016-2017 and cohort 2015-2016, were each checked for normality of distribution using the Shapiro-Wilk test and for equal variances with Levene’s test. Thereafter, an independent samples t-test was conducted for statistical differences in outcome of written exams between the 2016-2017 and the 2015-2016 student cohorts. A paired-samples t-test was used to compare the outcomes in written exams between the repeaters first and second attempts (scale from 0 to 40). All tests were conducted using IBM SPSS Statistics (version 23) with P<0.05 as significance level.

Table 2. Response on different statements about the 3D Atlas of Human Embryology

<table>
<thead>
<tr>
<th>Given statements</th>
<th>Strongly positive (5)</th>
<th>Positive (4)</th>
<th>Neutral (3)</th>
<th>Negative (2)</th>
<th>Strongly negative (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical classes led to better learning and understanding of embryology</td>
<td>32 (35%)</td>
<td>42 (46%)</td>
<td>9 (10%)</td>
<td>3 (3%)</td>
<td>5 (6%)</td>
</tr>
<tr>
<td>The physical hand-painted embryology models were useful for learning embryology</td>
<td>16 (18%)</td>
<td>53 (58%)</td>
<td>12 (13%)</td>
<td>9 (10%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>The 3D atlas was useful for learning embryology</td>
<td>21 (23%)</td>
<td>47 (52%)</td>
<td>12 (13%)</td>
<td>8 (89%)</td>
<td>3 (3%)</td>
</tr>
<tr>
<td>3D atlas led to better understanding of embryology compared to the physical models</td>
<td>25 (28%)</td>
<td>39 (43%)</td>
<td>17 (19%)</td>
<td>6 (7%)</td>
<td>4 (4%)</td>
</tr>
<tr>
<td>I appreciated the supervision during the practical class</td>
<td>17 (19%)</td>
<td>53 (58%)</td>
<td>18 (20%)</td>
<td>3 (3%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>
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Results

Questionnaire
A total of 91 respondents of the 207 students of the cohort (44%) completed the questionnaire. The demographics of the respondents are summarized in table 1. Of the 77 new students, 61 students would recommend the practical classes in their current form, versus 8 of the 14 repeaters. A Chi-square test for independence (with Yates’ Continuity Correction) indicated no significant association between type of student (i.e. new student or repeater) and whether they recommend practical classes in their current form for future practical classes, \( \chi^2 (1, N = 91) = 1.72, p = 0.19, \phi = 0.17 \). The results on the students’ opinions on the questionnaire statements are shown in table 2 and figure 3. For each statement the median of the responses was in category 4 and 5. Practical classes were much appreciated (by 81% of respondents). The same is true for the supervision during these classes (80%). The use of physical and virtual 3D models each reached an appreciation of 76% and 75%, respectively. Despite this similarity, 71% of the students agreed with the statement that the 3D atlas led to better understanding of embryology than the physical models.

Responses on the open-ended questions are categorized by theme and sub-theme, and summarized in table 3. Five key themes were identified: Interface 3D atlas, Technical issues, Practical classes, Use of 3D atlas, and Supervision by embryologists. The key theme Practical classes was further subdivided in three subthemes: Format, Amount of time and Assignments.

Half of the respondents gave written feedback on the Interface of the 3D Atlas of Human Embryology. The majority of the feedback (81%) was positive and students labeled the interface as intuitive and easy to understand and use, as is illustrated by the following comment: “You don’t really need much explaining to use the program, everything goes without saying”. To a lesser extend respondents commented that the 3D atlas being in English made recognizing certain structures harder, because the embryology lectures were in Dutch using Latin terminology.

Of all respondents, 22% spoke about Technical issues. The main issues raised included problems with internet connection and downloading the needed free software (i.e. Adobe Reader® X or higher, available from http://www.adobe.com/downloads/). However, students praised the supervisors’ help solving the technical issues, resulting in only one student who could not do the assignments on his or her own laptop.

The most frequent comment in the theme Practical classes (subtheme Time) was “too little time for all the assignments”. Comments associated with the theme Practical classes (subtheme Format) most frequently stated the usefulness of the practical classes. One respondent described the classes as “an excellent preparation for the written exam”, while others wrote about the practical classes giving insight in the level of knowledge on certain subjects. Furthermore, respondents liked the independence they were given during practical class. Comments associated with the subtheme Assignments were merely positive, labeling them as “very instructive”. Some respondents mentioned a few unclear assignments and wrong references in the texts.

Another important theme was Use of 3D atlas, which was highly appreciated by the majority of the respondents. The following comment from a respondent illustrates this point: “The 3D atlas really helps to visualize the embryonic development”. Furthermore, students mentioned that the 3D atlas helped giving them insight in certain embryonic processes that they did not fully understand yet during the embryology lectures. Supervision by the embryologists also received positive feedback from the respondents. The following comment from a respondent illustrates this
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point: “The supervisors had much knowledge on the subjects, it was nice having them during the practical classes because they could explain hard assignments very easily”. Respondents also mentioned to “like working in a group of five students” because it enabled them to discuss the assignments with each other. Be that as it may, an important issue mentioned by several respondents was that they would like to have more classical moments during the practical class to evaluate some hard questions with the whole group.

Test results written exam
The students’ exam results of both the 2015-2016 ($W(175) = 0.99, p = 0.33$) and 2016-2017 cohort ($W(169) = 0.98, p = 0.06$) were normally distributed. Furthermore, Levene’s test for equality of variances showed equal variances among both new students and repeater cohorts test results ($p = 0.13$). An independent-samples t-test was conducted to compare exam results of the 2016-2017 to the 2015-2016 cohort. There was no significant difference in scores for the 2015-2016 cohort ($M = 24.33, SD = 4.94$) and the 2016-2017 cohort ($M = 25.01, SD = 5.67$); $t(342) = -1.18, p = 0.24$, two-tailed). The magnitude of the difference in the means (mean difference = -0.67, 95% CI: -1.80 to 0.45) was small (eta squared = 0.004).

A paired-samples t-test was conducted to evaluate the impact of the 3D atlas on repeaters’ scores ($N = 18$) on the final exam in the two academic years. There was a statistically significant increase in students’ score from 2016 ($M = 18.61, SD = 3.97$) to 2017 ($M = 23.17, SD = 3.43$); $t(17) = -5.23, p < 0.001$ (two-tailed). The mean increase in students’ scores was 4.56 with a 95% confidence interval ranging from 2.72 to 6.39. The eta squared statistic (0.62) indicated a large effect size.

Fig. 3. Responses on different statements on the 3D Atlas of Human Embryology. For details, see table 2. Note that although the 3D atlas led to better understanding of the embryology compared to the physical models, the students similarly appreciated the usefulness of physical hand-painted models and the 3D atlas for learning embryology. Together with the highly appreciated supervision during the practical classes these results underscore the usefulness of a blended learning approach in embryology education.
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Discussion

Embryonic development is seen by many (bio)medical students as tough and puzzling. A lack of interactive 3D visualization of the embryonic growth processes is one of the reasons for this opinion. The current study was conducted to find out whether the 3D Atlas of Human Embryology (De Bakker et al., 2016) has a significant added educational value to the curriculum of a (bio)medical student. The use of the interactive 3D atlas in embryology practical classes was hypothesized to improve the students learning experience. We found indeed that the students appreciated the interactive 3D atlas in addition to the lectures and use of the physical hand-painted models, but its use did not significantly improve the students test scores.

The test results of the written exam showed no significant difference in the over-all scores of the 2015-2016 versus the 2016-2017 cohorts. However, the paired t-test that was conducted to evaluate the impact of the 3D atlas on repeaters’ scores on the final exam did show a statistically significant increase in students’ score from 2016 to 2017 (close to 25% higher scores on average). However, since the repeaters took the course for a second time, this increase cannot be plainly explained by the use of the 3D atlas this year.

Results from the questionnaire show that the students appreciated the practical classes in general, scoring a median of 4 out of 5 when asked whether the classes led to a better understanding of embryology. The results showed that the use of the 3D digital atlas in practical class was highly appreciated by the students, especially because the atlas helped to visualize embryological processes that they did not fully understand yet during the classroom lectures. Furthermore, students labeled the interface of the 3D atlas as intuitive and easy to understand. Interestingly, students also mentioned to desire the use of the physical hand-painted embryological models, next to the digital 3D atlas. Furthermore, students had positive experience with embryologists as practical class supervisors, which resulted in a positive effect on their learning experience. This indicates that the practical classes cannot simply be replaced by online assignments.

Table 3. Summary of student responses (total n = 91) to the open-ended questions

<table>
<thead>
<tr>
<th>Theme</th>
<th>Subtheme (where applicable)</th>
<th>Number of student comments (percentage of total)</th>
<th>Number of positive comments (percentage)</th>
<th>Number of negative comments (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface 3D atlas</td>
<td></td>
<td>47 (52%)</td>
<td>38 (81%)</td>
<td>9 (19%)</td>
</tr>
<tr>
<td>Technical issues</td>
<td></td>
<td>20 (22%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Practical classes</td>
<td>Format</td>
<td>19 (21%)</td>
<td>16 (84%)</td>
<td>3 (16%)</td>
</tr>
<tr>
<td></td>
<td>Amount of time</td>
<td>15 (16%)</td>
<td>13 (87%)</td>
<td>2 (13%)</td>
</tr>
<tr>
<td></td>
<td>Assignments</td>
<td>2 (2%)</td>
<td>1 (50%)</td>
<td>1 (50%)</td>
</tr>
<tr>
<td>Use of 3D atlas</td>
<td></td>
<td>17 (19%)</td>
<td>14 (82%)</td>
<td>3 (18%)</td>
</tr>
<tr>
<td>Supervision by embryologists</td>
<td></td>
<td>7 (8%)</td>
<td>7 (100%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>
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The use of the interactive 3D atlas for teaching human embryology fits well in a modern blended curriculum, in which traditional lectures are combined with online learning (Graham, 2013). The use of blended approaches may serve to enhance the students’ motivation, satisfaction and learning experience. In research done by Woltering and colleagues (2009) motivation, subjective learning gains and satisfaction achieved significantly higher ratings by the blended learning students compared with the students learning by traditional methods. The fact that the students clearly expressed their preference to use both the interactive 3D atlas and the hand-painted physical models during the practical classes further emphasizes the beneficial effects of a blend of different educational materials, and shows that the digital atlas should not totally replace current embryology models.

This study also has its limitations. It was the first time that the students worked with 3D embryos of the 3D Atlas of Human Embryology, and so they were not experienced users of the interface. Furthermore, the 3D atlas was not used during the classroom lectures. Therefore, in future courses the 3D atlas will already be presented during the lectures to make the students already familiar with the interface. Furthermore, students will be asked to download the required version of Adobe Reader® (http://www.adobe.com/downloads/), before the start of the practical classes to avoid downloading issues during class.

Conclusion

The 3D Atlas of Human Embryology (De Bakker et al., 2016) proved to be a valuable resource to accompany embryology lectures to facilitate understanding of the intricate developmental processes. Since the students highly appreciated the combination of both the physical 3D hand-painted embryology models and the digital 3D atlas during practical classes, the atlas perfectly fits a blended learning curriculum.

Acknowledgments

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References


