

## Online testable concept maps: benefits for learning about the pathogenesis of disease

Veronica Ho, Rakesh K Kumar & Gary Velan

**CONTEXT** Concept maps have been used to promote meaningful learning and critical thinking. Although these are crucially important in all disciplines, evidence for the benefits of concept mapping for learning in medicine is limited.

**METHODS** We performed a randomised crossover study to assess the benefits of online testable concept maps for learning in pathology by volunteer junior medical students. Participants ( $n = 65$ ) were randomly allocated to either of two groups with equivalent mean prior academic performance, in which they were given access to either online maps or existing online resources for a 2-week block on renal disease. Groups then crossed over for a 2-week block on hepatic disease. Outcomes were assessed using timed online quizzes, which included questions unrelated to topics in the pathogenesis maps as an internal control. Questionnaires were administered to evaluate students' acceptance of the maps.

**RESULTS** In both blocks, the group with access to pathogenesis maps achieved significantly higher average scores than the control group on quiz questions related to topics covered by the maps (Block 1:  $p < 0.001$ , Cohen's  $d = 0.9$ ; Block 2:  $p = 0.008$ , Cohen's  $d = 0.7$ ). However, mean scores on unrelated questions did not differ significantly between the groups. In a third block on pancreatic disease, both groups received pathogenesis maps and collectively performed significantly better on quiz topics related to the maps than on unrelated topics ( $p < 0.01$ , Cohen's  $d = 0.5$ ). Regression analysis revealed that access to pathogenesis maps was the dominant contributor to variance in performance on map-related quiz questions. Responses to questionnaire items on pathogenesis maps were overwhelmingly positive in both groups.

**CONCLUSIONS** These results indicate that online testable pathogenesis maps are well accepted and can improve learning of concepts in pathology by medical students.

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Department of Pathology, School of Medical Sciences, University of New South Wales, Sydney, New South Wales, Australia

*Correspondence:* Gary Velan, MBSS, DipHEd, PhD, Department of Pathology, School of Medical Sciences, University of New South Wales, Sydney, New South Wales 2052, Australia.  
Tel: 00 61 2 9385 1278; E-mail: [g.velan@unsw.edu.au](mailto:g.velan@unsw.edu.au)

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**INTRODUCTION**

The constant growth in the body of knowledge in medicine requires students and practitioners to engage in meaningful, lifelong learning.<sup>1</sup> The study of pathology in particular demands an integrated understanding of concepts and ideas (i.e. of physiological functions, disease processes and their clinical manifestations). To these ends, concept mapping holds much promise.<sup>2</sup>

Developed by Novak and Gowin in the 1970s, concept maps are graphical tools for the organisation and representation of knowledge. Such maps are comprised of concepts (a regularity in events or objects) that are linked by lines or arrows labelled with linking phrases.<sup>3</sup> The fundamental aim of concept mapping is to promote meaningful learning. Shifting the responsibility for learning onto the student rather than the instructor, meaningful learning is distinguished from rote learning by its representation of the integration of new knowledge with existing understanding.<sup>4</sup> This integration of new information into an existing framework is believed to aid in the retention and application of knowledge.<sup>5</sup>

Concept mapping has been shown to improve results in problem-solving tests, which require the recall, transfer and application of knowledge.<sup>6</sup> Even when students are simply provided with an expert map rather than being asked to construct their own, concept maps can aid learning by reducing cognitive load and enhancing the understanding of relationships between different ideas, providing multiple retrieval paths.<sup>7</sup> Concept mapping is thus thought to enhance the development of critical thinking and problem-solving skills.<sup>8</sup>

Two main types of concept maps are used to promote learning. One requires students to construct their own maps by creating linking phrases between concepts, whereas the other (sometimes referred to as a 'scaffolded approach') involves the selection of linking phrases from a menu. The former method has been considered superior for several reasons,<sup>9</sup> including: (i) it more accurately reflects differences between students' knowledge structures; (ii) it provides more opportunities for demonstrating students' partial understanding and misconceptions; (iii) it provides students with more scope to reveal their understanding; and (iv) it elicits more high-order cognitive processes, such as explaining and planning. Nevertheless, the complexity of this method creates difficulties in assessing students'

work. The latter (scaffolded) method might be beneficial for novices in the discipline<sup>7</sup> and is also more practical as a tool for assessment because the number of potential permutations is reduced and the method is therefore more amenable to computer-based scoring.

However, despite the potential benefits of concept maps, they are often met with initial resistance from both students and instructors. For teachers, problems in evaluating maps may be attributed to the highly idiosyncratic nature of the maps produced, which reflect differences in knowledge structure between individuals.<sup>10</sup> Students may perceive concept mapping as a study tool that requires an unreasonable amount of time and effort,<sup>11</sup> particularly when traditional methods of assessment concentrate on measuring students' mastery of distinct pieces of knowledge during a course, rather than how well students have integrated such knowledge. Thus student motivation to learn new methods of integrating understanding can be low; students may find it difficult to directly observe the benefits of doing so and have little recognition of how concept maps might improve their academic results.<sup>12</sup> Therein lies one of the major struggles in incorporating concept maps into medical education.

Nevertheless, the use of scaffolded expert maps (which include blank spaces to be filled in) may be beneficial for introducing students to concept mapping. Compared with students' construction of their own maps, using either a paper-and-pencil method or a computer program, the use of scaffolded maps resulted in higher performance in subsequent tests.<sup>13</sup> It has been hypothesised that the lower cognitive load associated with scaffolded maps facilitates a sharper focus on the concepts involved.<sup>13</sup> Cognitive load theory assumes a limited working memory for novel information, whereby learning occurs through the organisation of new information into cognitive schemas in long-term memory. Cognitive load is comprised of the inherent load of what is to be learned, the load imposed by the manner in which information is presented, as well as the load used to produce and organise schema and thus learn. As human working memory is limited, a lower cognitive load is desirable to maximise learning.<sup>14</sup>

Providing immediate feedback to students also fosters higher motivation to learn and positive attitudes towards concept mapping itself.<sup>13</sup> Although attempts have been made to design automated systems for providing feedback to students on maps created online, the use of such systems remains

restricted. Many are compatible only with concept maps that have been constructed with a predetermined set of concepts or linking phrases.<sup>15,16</sup> Nevertheless, students given instantaneous feedback were found to make significantly better progress in learning, as well as to have better attitudes towards learning.<sup>15</sup>

However, there is limited evidence for the benefits of concept mapping in medicine<sup>10</sup> and in pathology in particular.<sup>16</sup> Online testable pathogenesis maps are scaffolded concept maps relating to disease processes. They are pre-constructed and key concepts or linking phrases are removed so that they can be 'dragged and dropped' into place by students. Instantaneous feedback is provided upon completion of each map. To determine whether such maps are an acceptable and effective learning tool, we designed a randomised crossover trial to evaluate both the quantitative and qualitative impact of online testable pathogenesis maps on the learning of pathology by medical students, compared with traditional learning methods.

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## METHODS

### Participants and study design

The study participants were medical students in Years 1 and 2 enrolled in Phase 1 of a 6-year undergraduate medicine programme. Learning in Phase 1 of the programme is scenario-based, integrated between disciplines, and vertically integrated for Year 1 and 2 students. Volunteer students entering Health Maintenance B, an integrated 8-week course comprising three blocks that focus on renal, hepatic and pancreatic disease, respectively, were recruited by broadcast e-mail prior to the commencement of the course.

Sixty-five participants were randomised into two study groups, Group 1 ( $n = 33$ ) and Group 2 ( $n = 32$ ), such that each group had similar numbers of Year 1 (Group 1:  $n = 11$ ; Group 2:  $n = 10$ ) and Year 2 (Group 1:  $n = 22$ ; Group 2:  $n = 22$ ) students. Prior academic performance, measured by mean  $\pm$  standard error of the mean (SEM) weighted average mark (WAM) did not differ significantly between groups (Group 1:  $68.9 \pm 1.7\%$ ; Group 2:  $70.3 \pm 1.6\%$ ;  $p = 0.59$ ). Importantly, the mean WAM of participants who completed at least one component of the study ( $n = 59$ ) did not differ significantly from that of non-participants ( $n = 471$ ) in Phase 1 of the medicine programme (participants:  $69.6 \pm 1.2\%$ ; non-participants:  $67.0 \pm 0.4\%$ ;

$p = 0.54$ ). Moreover, the WAM of participants who completed all components of the study ( $n = 37$ ) did not differ from that of those who did not complete all components ( $n = 28$ ) (completers:  $70.0 \pm 1.5\%$ ; non-completers:  $69.0 \pm 1.7\%$ ;  $p = 0.40$ ).

During the renal disease scenario, Group 1 received secure access via the university's learning management system to testable online pathogenesis maps relating to key concepts in pathology covered in that block (acute kidney injury and chronic kidney disease), whereas participants in Group 2 were provided with links to existing online resources (*Robbins Basic Pathology*, 9th edition online via MD Consult) relating to the same concepts. During the hepatic disease block, Group 2 crossed over to receive access to testable online pathogenesis maps relating to key concepts in pathology covered in that block (alcoholic liver disease and complications of cirrhosis), and Group 1 was provided with links to existing online resources relating to the same concepts. Both groups were provided with access to testable online pathogenesis maps covering key concepts in pathology (acute pancreatitis and diabetes mellitus) during the final block on pancreatic disease.

At the end of each 2-week block, both groups completed a secure time-limited online assessment. The students exposed to pathogenesis maps in each block also completed an online questionnaire relating to their perceptions of pathogenesis maps. Participants were informed that assessment results would be kept confidential, that the questionnaire would be anonymous and that participation would have no impact on their academic standing. All participants were provided with access to all pathogenesis maps at the conclusion of the trial. Approval for this study was obtained from the University of New South Wales Human Research Ethics Committee.

### Development of pathogenesis maps

Six concept maps were constructed using the free-ware program CmapTools™ (Florida Institute for Human and Machine Cognition, Pensacola, FL, USA). These maps related to key concepts in pathology covered in the Health Maintenance B course; two maps per block were provided as described above.

All maps were revised and edited several times in collaboration with senior members of academic staff in the Department of Pathology. The final maps were converted into a testable format using Questionmark Perception™ (Questionmark Computing

Ltd, London, UK), which facilitates the creation of items for which participants can ‘drag and drop’ missing nodes into each map. Missing nodes included key concepts and linking phrases for each disease process. An example of a testable pathogenesis map is shown in Fig. 1. The pathogenesis maps were made available online to participants, together with automated feedback on completion. An example of a completed pathogenesis map provided as feedback for students is shown in Fig. 2. Throughout each 2-week block of study, participants in the group receiving the maps were provided with unlimited access.

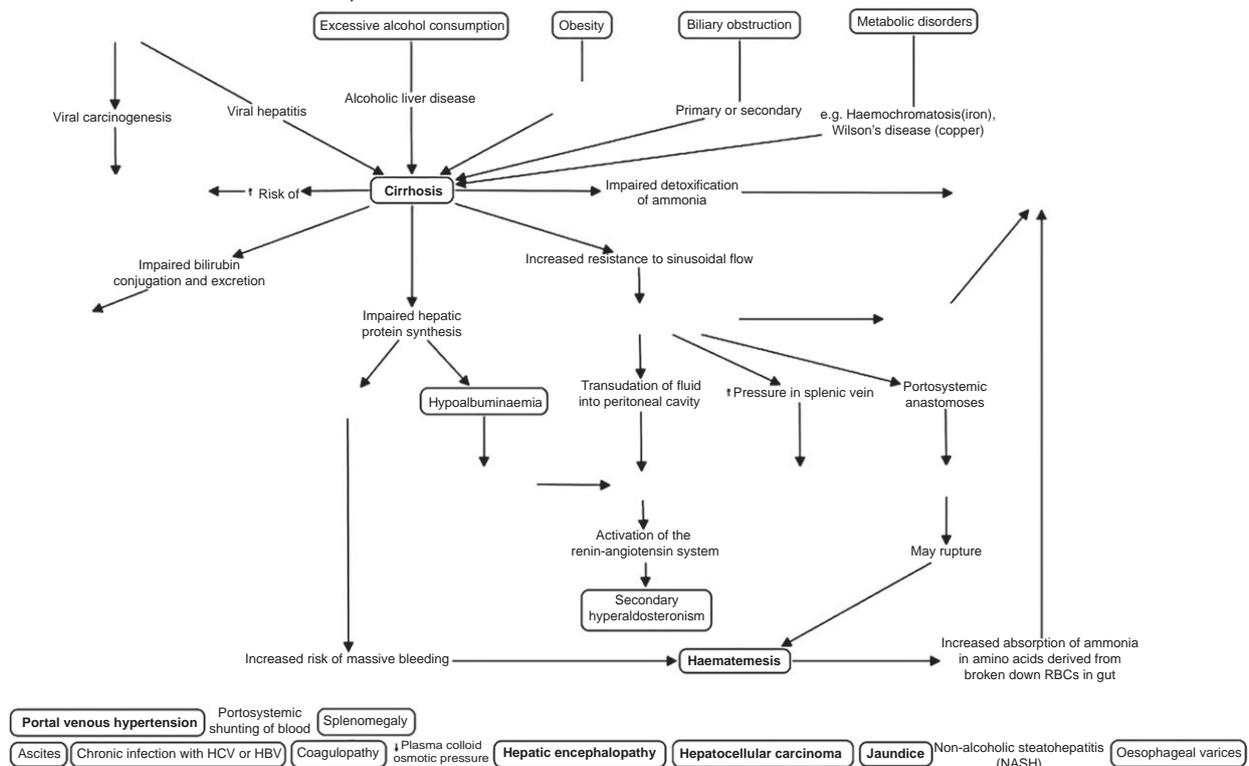
**Online quizzes and questionnaires**

The online quizzes each comprised between 15 and 19 objective items, approximately half of which related to the diseases covered by the pathogenesis maps. Importantly, each quiz also contained questions relating to concepts in pathology covered in that block of study, but unrelated to the topics of the pathogenesis maps. Those questions functioned as internal controls and were evaluated by senior members of academic staff in the Department of

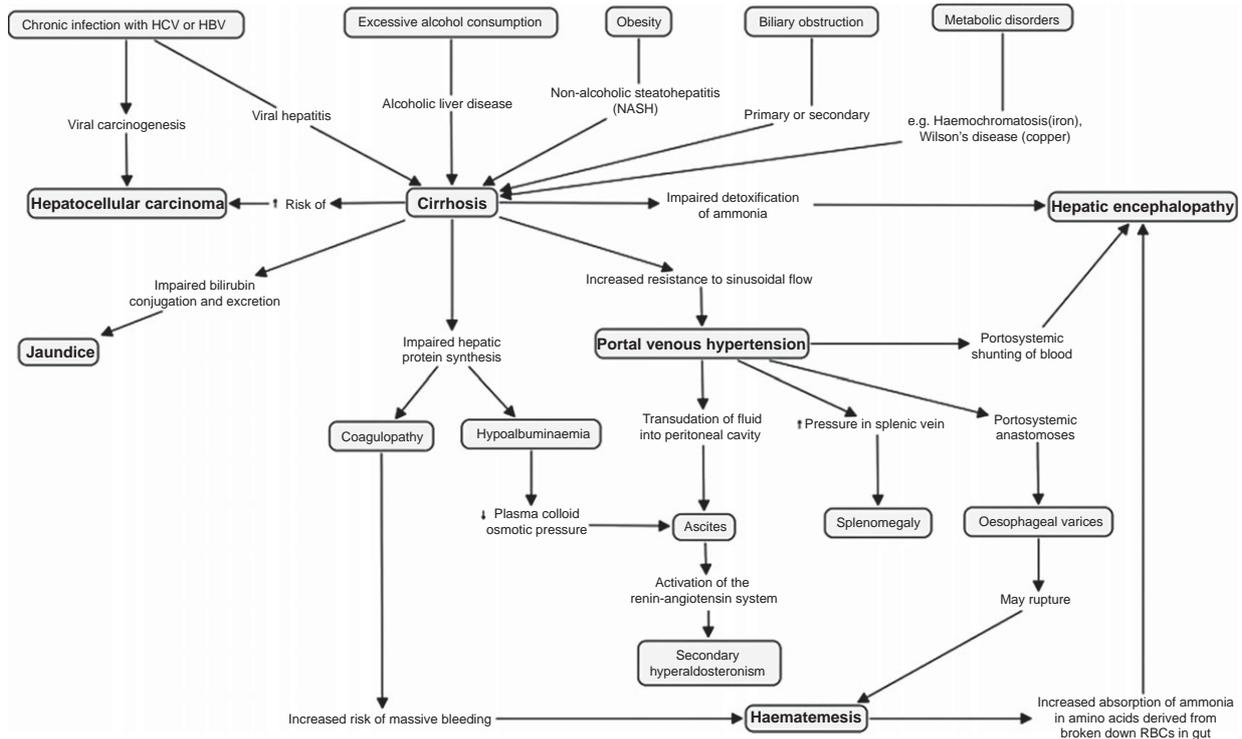
Pathology as being at least as difficult as the map-related questions.

The quizzes utilised objective items, with the exception of one question in each quiz which asked students to report the amount of time (in hours) they had spent studying topics in pathology during that block. The majority of the questions were of the ‘assertion–reason’ format wherein an assertion and reason are provided and the student is asked to consider whether both statements are correct and, if so, whether the reason correctly explains the assertion. This style of question seeks to assess students’ understanding of cause-and-effect relationships in the pathogenesis of disease. An example of an assertion–reason question on a map-related topic from the hepatic disease quiz is: ‘Alcoholic cirrhosis is reversible with abstinence BECAUSE regeneration of hepatocytes in the cirrhotic liver leads to restoration of hepatic architecture.’ In this case, both the assertion and the reason are incorrect statements. As with all items in the quizzes, such questions interrogated students’ understanding of relationships in the pathogenesis of disease. However, the answers could not be directly ascertained from the patho-

By selecting appropriate terms from below the image and dragging them into the correct positions, indicate the sequence of events that lead to the development of cirrhosis of the liver, its clinical manifestations and complications.



**Figure 1** An example of a testable pathogenesis map on the development and complications of cirrhosis



**Figure 2** An example of a completed pathogenesis map provided as feedback

genesis maps. Such questions thus provided assurance that students had actually gained an understanding of the disease process, rather than simply benefiting from the provision of more efficient or tailored access to information related to the test questions.

The remaining items were multiple-choice questions (MCQs) in which participants were asked to select the single best answer, again focusing on pathogenesis.

Each quiz underwent several revisions following feedback from senior members of academic staff in the Department of Pathology. Importantly, staff members were asked to evaluate the questions to ensure that the level of difficulty was consistent across both map-related and unrelated topics. The quizzes were delivered securely via the university's learning management system using Questionmark Perception™. At the beginning of each block of study, both groups were informed of which topics would be included in the quiz and were provided with links to existing online resources for those topics not covered by pathogenesis maps. Participants were asked to complete each 30-minute timed quiz under examination conditions (i.e. with no outside assistance, online references or textbooks) and to verify that they did so in accordance with a code of

honour. Immediate automated feedback was provided to participants following the submission of their answers for each quiz.

For groups with access to pathogenesis maps during that block, an online questionnaire was made available using Questionmark Perception™ immediately following the quiz. The questionnaire aimed to ascertain students' opinions on pathogenesis maps as an educational resource using a scale of 1–10 (1 = low, 10 = high). Participants were also asked to rate different aspects of their experiences with pathogenesis maps on a 5-point Likert scale. These questionnaire items had been utilised previously<sup>16</sup> and had been demonstrated to have high internal consistency (Cronbach's  $\alpha > 0.8$ ). Open-ended questions enabled participants to comment on the strengths and weaknesses of the maps, as well as to provide suggestions and feedback for improvements and future use.

### Statistical analysis

The reliability of online quizzes was determined using Cronbach's alpha. Unless otherwise stated, all quantitative data are provided as mean  $\pm$  SEM percentage scores. Statistical analysis was performed using unpaired Student's *t*-tests to compare the groups with respect to mean WAM and mean

performances on online quizzes, as well as hours of study during each block. A paired *t*-test was used to compare mean scores for related and unrelated questions in the pancreatic disease quiz for the combined groups. Effect sizes were calculated using Cohen's *d*. Regression analysis was performed to determine the proportion of variance in quiz scores accounted for by exposure to pathogenesis maps, prior academic performance and hours of study. For Likert scale items in the questionnaire, percentages of responses in agreement were calculated (i.e. percentage sums of 'strongly agree' and 'agree' responses). For questions requiring ratings out of 10 (1 = low, 10 = high) on the overall value of pathogenesis maps as a learning tool, comparisons of median ratings between groups were performed using Mann–Whitney tests.

Open-ended responses to online questionnaire items were exported into a spreadsheet to facilitate qualitative analysis. Common themes were then

identified in relation to positive features of concept maps and areas for improvement. Responses were then grouped, coded and analysed according to the emergent themes.

## RESULTS

### Renal disease quiz outcomes

A total of 27 participants from Group 1 and 28 participants from Group 2 completed the online quiz for the renal disease scenario (Cronbach's  $\alpha = 0.7$ ), during which Group 1 was provided with access to the pathogenesis maps and Group 2 acted as a control group. There was no significant difference between the mean hours of study reported by the two groups (Table 1). The mean overall quiz score was significantly higher for Group 1 than Group 2. This difference was accounted for by the significantly better mean performance on quiz questions

Table 1 Results on quizzes on renal disease, hepatic disease and pancreatic disease

Scenario	Score, %, mean $\pm$ SEM			
	Overall quiz	Topics related to pathogenesis maps	Topics unrelated to pathogenesis maps	Hours of study, mean $\pm$ SEM
Renal disease quiz results				
Group 1 (with maps, n = 27)	56.0 $\pm$ 1.7	55.9 $\pm$ 3.1	56.4 $\pm$ 2.5	3.0 $\pm$ 0.4
Group 2 (no maps, n = 28)	46.1 $\pm$ 2.3	39.2 $\pm$ 3.2	55.7 $\pm$ 3.5	2.5 $\pm$ 0.3
	p < 0.01 d = 0.8*	p < 0.01 d = 0.9*	p = 0.88	p = 0.33
Hepatic disease quiz results				
Group 1 (no maps, n = 26)	56.8 $\pm$ 3.3	58.0 $\pm$ 3.4	54.5 $\pm$ 4.5	2.5 $\pm$ 0.3
Group 2 (with maps, n = 18)	66.1 $\pm$ 3.3	72.2 $\pm$ 3.7	54.6 $\pm$ 4.2	3.1 $\pm$ 0.4
	p = 0.06	p < 0.01 d = 0.7*	p = 0.98	p = 0.32
Pancreatic disease quiz results				
Group 1 (with maps, n = 22)	59.0 $\pm$ 3.2	63.6 $\pm$ 4.1	53.3 $\pm$ 3.8	3.0 $\pm$ 0.6
Group 2 (with maps, n = 18)	59.4 $\pm$ 4.3	62.5 $\pm$ 4.3	55.6 $\pm$ 5.3	2.7 $\pm$ 0.9
	p = 0.94	p = 0.85	p = 0.72	p = 0.76
Combined groups	59.2 $\pm$ 2.6	63.1 $\pm$ 2.9 p < 0.019 d = 0.5*	54.3 $\pm$ 3.1	2.8 $\pm$ 0.5

SEM = standard error of the mean

\* Cohen's *d* effect size measures are indicated where significant differences were found between groups using Student's *t*-tests

related to the topics covered by the pathogenesis maps in Group 1 compared with Group 2, with a large effect size (Cohen's  $d = 0.9$ ). Both groups performed similarly on quiz questions unrelated to the topics covered by the pathogenesis maps (Table 1).

### Hepatic disease quiz outcomes

During the second block, Group 2 was provided with access to online testable pathogenesis maps and Group 1 was provided with links to existing online resources. Twenty-six participants in Group 1 and 18 participants in Group 2 completed the online quiz (Cronbach's  $\alpha = 0.6$ ) relating to concepts in pathology in this block. Again, there was no significant difference between the groups for reported hours of study. The overall mean scores for the hepatic disease quiz did not differ significantly between groups. However, Group 2 performed significantly better on quiz questions related to the topics covered by the maps than Group 1, as seen in Table 1, with a medium effect size (Cohen's  $d = 0.7$ ). Mean scores on questions unrelated to the map topics were almost identical in both groups.

### Pancreatic disease quiz outcomes

For the final block, both groups were provided with access to online pathogenesis maps. Forty participants (22 from Group 1 and 18 from Group 2) completed the quiz (Cronbach's  $\alpha = 0.6$ ). As Table 1 shows, there was no significant difference between the groups in terms of overall performance on the online quiz, nor on questions either related or unrelated to topics covered in the maps. Nor was there a significant difference between groups in the reported mean hours of study. Collectively, however, both groups performed significantly better on topics related to pathogenesis maps than unrelated topics (Table 1), with a medium effect size (Cohen's  $d = 0.5$ ).

### Regression analysis

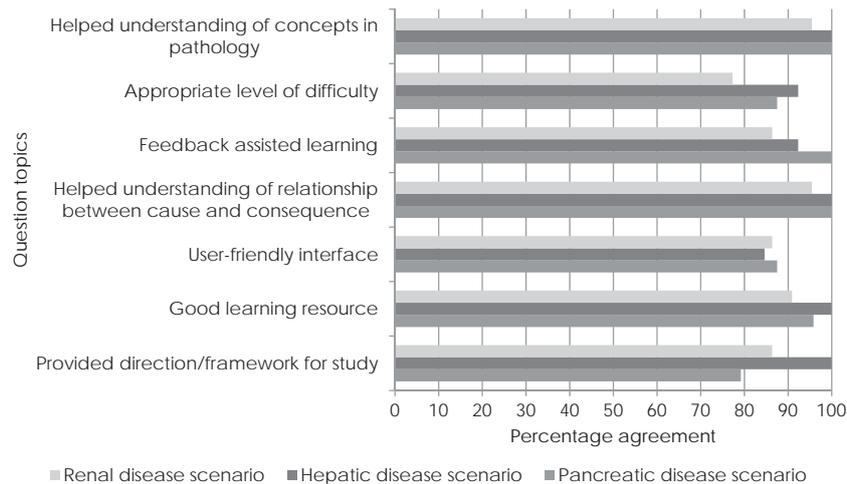
The quiz results for Blocks 1 and 2 were aggregated to evaluate the major factors contributing to variance in map-related quiz scores. Regression analysis revealed that exposure to pathogenesis maps and WAM contributed significantly to the variance in scores, but hours of study did not. In this model, these factors combined to account for 21.8% of the variance ( $p < 0.001$ ). Exposure to pathogenesis maps was the most powerful predictor, accounting for 13.6% of the variance in scores, whereas WAM accounted for 6.8% of the variance.

### Questionnaire outcomes

A total of 23 participants from Group 1 completed the questionnaire following the renal disease quiz, 14 participants from Group 2 completed the questionnaire following the hepatic disease quiz and 24 participants from both groups combined completed the questionnaire following the pancreatic disease quiz. When participants were asked to rate the value of pathogenesis maps as an educational resource, responses were resoundingly positive, with median scores of 8 out of 10 for the renal disease block (interquartile range [IQR]: 7.0–9.0), 9 out of 10 for the hepatic disease block (IQR: 8.0–10) and 9 out of 10 for the pancreatic disease block (IQR: 8.5–10). The median ratings did not differ significantly between groups, as determined by a Mann–Whitney test. A summary of responses to Likert scale items on participants' perceptions of pathogenesis maps is provided in Fig. 3. In summary, a large majority of participants considered that the maps: enhanced their learning of pathology, particularly the relationships between the causes and consequences of disease; were pitched at an appropriate level of difficulty; were user-friendly; provided a framework for further study, and represented valuable learning resources overall.

Qualitative analysis of open-ended questionnaire responses resulted in the emergence of several common themes in response to the question: 'What are the strengths of online pathogenesis maps as a learning resource?' There were a total of 43 positive comments, many of which encompassed several themes. The common themes were: demonstrating links between cause and effect relationships in pathogenesis (LI,  $n = 27$ ); providing an overview or summary of the disease process (OV,  $n = 19$ ); enhancing overall understanding (UN,  $n = 11$ ); providing feedback (FE,  $n = 5$ ); promoting self-directed learning (SDL,  $n = 5$ ); providing a visual learning resource (VI,  $n = 4$ ), and integrating material from different sources (IN,  $n = 3$ ). Representative comments and their associated theme codes are provided in Table 2. The following comment encompasses a number of themes (IN, OV, SDL, LI):

Drew concepts from different lectures together and gave a great overview. Prompted critical thinking and self-directed research by "joining the dots" and providing a thorough explanation of the pathogenesis of different diseases.



**Figure 3** Likert scale questionnaire responses (percentage agreement [i.e. 'agree' and 'strongly agree']) for the renal disease scenario (Group 1,  $n = 23$ ), hepatic disease scenario (Group 2,  $n = 14$ ) and pancreatic disease scenario (both groups,  $n = 24$ )

Three common themes emerged in response to the question: 'How could your experience of using online pathogenesis maps be improved?' There were a total of 14 comments, most of which related to improvements in the user interface (UI,  $n = 7$ ), requests for more information (MI,  $n = 5$ ) or integration with other disciplines (DI,  $n = 3$ ). Within the UI theme, students commented on technical issues regarding browser compatibility and accessibility, particularly on the ability to fit the entire map on a computer screen. Within the MI theme, participants commented that the maps would benefit from more detail, both in the maps themselves and in the feedback provided, as was evident in comments that requested '...an explanation as to why something was wrong' and 'detailed solutions instead of just the complete map'. These included suggestions that links within the pathogenesis maps to additional resources or images could be provided.

## DISCUSSION

These results demonstrate that online testable concept maps are effective in fostering the learning of pathology by medical students. Each of the groups exposed to pathogenesis maps performed significantly better than the non-exposed group on questions related to the topics covered in the pathogenesis map. Furthermore, the effect sizes were medium to large and thus added weight to these findings. It was clear that there was no carryover effect of exposure to maps between blocks of study. Given the wide differences in subject matter among blocks and the topic-specific nature of the

pathogenesis maps, this lack of carry-over had been anticipated. Importantly, performance on questions not related to the maps did not differ significantly between groups in any of the three blocks of study.

A paired *t*-test revealed that participants in both groups exposed to the same pathogenesis maps performed significantly better on average on questions related to the maps than on unrelated questions in the quiz on pancreatic disease. This result further reinforces the likelihood that exposure to the maps improved students' learning. Indeed, exposure to pathogenesis maps was the primary factor responsible for variance in quiz scores on map-related topics. Thus, although we must acknowledge that sample sizes in this study were small, it seems reasonable to conclude that exposure to the pathogenesis maps was responsible for the observed improvement in performance.

The amount of time spent studying topics in pathology during each block, as reported by students, did not differ significantly between groups. Furthermore, time spent studying was not a significant predictor of score on map-related questions. From these data we infer that pathogenesis maps enhanced the learning of pathology in a time-efficient manner.

Students received the pathogenesis maps very well indeed: several students commented that using the maps had encouraged them towards further self-directed learning. This adds to the findings of previous studies,<sup>9,15,16</sup> which demonstrated that the use of testable online concept maps with associated

Table 2 Representative selection of open-ended comments from both groups on questionnaires on the strengths of the online pathogenesis map as a learning resource

Themes	Comments
LIV/IN	'I find the use of maps generally to be a very effective study tool particularly when there is a great deal of relationship and crossover between various processes/diseases. A map greatly assists in visualising a topic on a single "page" rather than having multiple resources'
UN	'The pathogenesis maps were extremely helpful for me in understanding complex concepts in a very clear, easy to understand, brief format. They cut down my study time and helped to clear things I was unsure of and confused about'
LI/FE	'They really test and make you think about links between areas. You can clearly see what areas you are not knowledgeable in'
L/UN	'Pathology is all about the study of function and dysfunction, with any function or dysfunction there are going to be causal pathways and I think pathogenesis maps are best suited to manifesting such causality. They give you not only the causes but the effects as well, allowing you to see how ultimately the two are connected. They reduce the need of the student to rote learn, allowing them to UNDERSTAND instead'
VI	'It visually allows me to understand the content (which was amazing)!
IN/OV/FE	'Helped integrate material in lectures and practs and clarify concepts. Provided the big picture, including risk factors of the diseases hence high clinical relevance. Showed up areas of strengths and weaknesses'
<p>FE = providing feedback; IN = integrating material from different sources; LI = demonstrating links between cause and effect relationships in pathogenesis; OV = providing an overview or summary of the disease process; UN = enhancing overall understanding; VI = providing a visual learning resource</p>	

feedback helped maintain enthusiasm and interest in topics studied. Notably, a previous study by our research group was a consecutive cohort study in

which the first cohort acted as the control group (receiving traditional teaching methods) and the second represented the study group (receiving access to online testable concept maps).<sup>16</sup> Outcomes were similarly measured through the completion of an online objective answer quiz and questionnaire. We believe that the present study provides stronger evidence of learning impact as a result of its randomised crossover design.

This study focused on the use of online concept maps by junior medical students in an undergraduate medicine programme. Students were introduced to the disease processes covered in the maps around the time they started to use the maps. Therefore, it is likely that students had a minimal level of prior understanding. Participants' acceptance of the testable online concept map as a tool that provides a framework for their personal study of pathology, as well as a learning resource in itself, is consistent with the argument proposed by O'Donnell *et al.*<sup>7</sup> that maps are particularly beneficial for students with little prior knowledge of a topic, who appear to benefit from the structure provided by maps. By summarising large amounts of information and providing students with an overview of pathological processes, online concept maps provide a ready-formed structure and may accordingly accelerate learning. Specifically, the drag-and-drop method of concept mapping used in the present study, as opposed to methods in which students construct their own maps, may be more acceptable because it is less time-consuming. Similarly to Chang *et al.*,<sup>13</sup> we found that scaffolded maps (such as our testable pathogenesis maps) have the advantage of allowing students to immediately focus on and learn key concepts and relationships. Given the overwhelmingly positive feedback from students, we believe that the online testable pathogenesis map is a valuable introduction to concept mapping for junior medical students.

Future studies might focus on the impact of such testable maps on learning in senior medical students. It is possible that such maps may conflict with existing knowledge frameworks and thus yield less benefit. Alternatively, senior students, once familiar with concept mapping, could be encouraged to explore a less structured approach to pathogenesis mapping, such as that involved in constructing a map from scratch. This would allow them to reflect on their own framework of understanding in an area of knowledge. It would also be of interest to perform a follow-up study with the present cohort in order to evaluate the long-term retention of knowledge.

Feedback from participants highlighted areas in which pathogenesis maps could be improved. Students were primarily concerned with ease of use and access to maps in terms of web browsers. These issues could be addressed prior to the use of maps in the future. Comments also indicated the opinion that maps would benefit from further detail and explanation, and the inclusion of links to additional resources, images or histological slides. Although these additions could be incorporated, if pathogenesis maps are to be used as a starting point and are to offer students a framework and direction for study, they may instead be presented separately.

### Limitations

Although we acknowledge that this study employed a relatively small sample size, it provided sufficient statistical power to adequately demonstrate significant differences between groups. Because the participants were volunteers, there may have been potential for selection bias (i.e. we may have unintentionally selected for students who were more highly motivated and able than their peers). However, the participants in this study did not differ significantly from their peers in demonstrated prior academic performance, which represents our best available measure of ability and motivation to study. Furthermore, the mean WAM of participants who completed all three online quizzes did not differ significantly from that of participants who failed to complete one or more quizzes. Therefore, we believe that selection bias was unlikely to have contributed significantly to our positive findings.

Some might also question the reliability of the online quizzes, given that Cronbach's  $\alpha$ -values of 0.6–0.7 are less than ideal. However, it should be noted that in the interests of validity, the quizzes were relatively broad, with each covering four different knowledge domains, and thus a reduction in the measured Cronbach's  $\alpha$ -value was inevitable.

Every effort was made to ensure that the quiz items focusing on diseases unrelated to the concept maps were matched in difficulty with items focusing on diseases covered by the concept maps. Nevertheless, although it is unlikely, it is possible that potential differences in difficulty between concept map-related and unrelated items may have confounded the results.

Participants' retrospective self-reports of time spent studying topics in pathology during each block might well be unreliable, as has been noted previ-

ously.<sup>17</sup> It is possible that use of an electronic diary in real time might have provided a better record, but this was not incorporated into our study. Nevertheless, we have no basis for believing that there was any systematic bias in the accuracy of such reports. Therefore, it seems reasonable to accept that there were no meaningful differences between groups in time spent studying during each block.

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### CONCLUSIONS

The results of this randomised crossover study indicate that online, testable, scaffolded concept maps are well accepted by junior medical students and can improve their learning of concepts in pathology. This form of concept mapping can be readily introduced and incorporated into courses of study within pathology, other medical disciplines and indeed any discipline in which cause and effect relationships are crucial. Although a larger sample size might provide more generalisable results, the findings of this study add to the body of evidence supporting the concept map as a means of promoting meaningful learning in the field of medicine and in pathology in particular.

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*Contributors:* VH contributed to the study design, developed the pathogenesis maps, quizzes and questionnaire, and drafted the manuscript. RK contributed to the study design, and critically reviewed and edited the pathogenesis maps and quizzes. GV contributed to the study conception and design, and critically reviewed and edited the pathogenesis maps, quizzes and questionnaire. All authors contributed to the critical revision of the paper and approved the final manuscript for submission.

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*Ethical approval:* this study was approved by the University of New South Wales Human Research Ethics Committee (no. HC13070).

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