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公 示

根据《新闻记者证管理办法》有关规定及《国家新闻出版署关于开展2024年第七版新闻记者证全国统一换发工作的通知》(国新出发函〔2024〕176号)要求,本单位全面梳理新闻记者证管理情况,逐一审核拟换证人员情况。现将拟换证人员名单予以公示。

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科教文汇

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人工智能背景下“互联网+智慧教育”新生态系统构建研究

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摘要：智慧教育是教育信息化的产物，依托“互联网+”技术打造“物联化、智能化、泛在化”的新型教育生态系统，已成为人工智能时代的研究热点。该文从人工智能背景出发，对比分析传统课堂和人工智能驱动下的智慧教育课堂在教学资源、教学场景、教学评价及教学管理方面的差异性，发现教与学的内在规律和影响因素，运用系统协同理论，立足宏观、中观、微观三个环境角度，构建“虚实环境+智慧课堂+智能评价”的三维新生态系统，形成人工智能与师生教学共同体，使得人工智能和教育教学领域深度融合，加快教育向高质量阶段发展。

关键词：人工智能；互联网+智慧教育；教育生态系统
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2017年，国务院印发《新一代人工智能发展规划》[1]，提出“围绕教育、医疗、养老等迫切民生需求，加快人工智能的创新应用”。近年来，以人工智能为代表的新兴技术开始在教育领域迅速发展。2021年12月，中央网络安全和信息化委员会印发《“十四五”国家信息化规划》[2]，提出“统筹制定全民数字技能教育推进方案”“推广和普及全民数字技能教育”。新规划的实施，推动教育行业加速形成以人工智能为核心、“互联网+智慧教育”深度融合的新教育生态系统。因此，如何在人工智能背景下将人工智能与教育相结合，充分利用“互联网+”技术助力教师能力发展，构建智慧教育课堂，进行教育信息化升级，打造人机交互的课堂教师教学与学生学习新模式，解决传统教育理论与实践脱节的问题，构建和谐教育生态系统，成为未来研究的重点领域。

1 研究意义与价值

1.1 国家层面

人工智能技术应用推进教育信息化快速发展，精准解决教育不能兼顾大规模与高质量的矛盾，促进教育变革，实现教育与智能化科学技术深度融合和创新发展。

1.2 学校层面

对教育产业的供给侧进行结构改革，改善学校基础教学设施，打造智慧教育环境，促进教师、学生角色转变，实现教师在人工智能背景下“互联网+智慧教育”数字素养、信息化教学能力及智慧教育水平提升，以点带面，促进产业链、人才链、教育链、信息链“四位一体”的协同化结构形成。

1.3 教学层面

重构教育生态系统，设计教育生态“环状”新系统，达到内容模块化与过程一体化，形成全流程化闭环结构，做到线上线下无边界，实现三维教学路径，有效弥补传统教育的缺陷，营造智能交互的学习环境，实现智能驱动、个性化与高效化，因材施教，提升人才培养质量，塑造智能时代智慧人才。

2 人工智能背景下智慧教育发展趋势

2.1 人工智能背景下智慧教育的特征

智慧教育借助互联网和数字化技术，提供多样化、个性化的互动学习体验，促进学生与教师、学生

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与学生之间的交流合作，实现学习的灵活化和高效化。

2.1.1 数字科技融合性

智慧教育利用互联网和数字化技术，将教育资源和服务进行数字化和在线化处理，给学生提供更广泛、便捷的学习机会，提升学习和教学效率。

2.1.2 资源多样化、内容个性化

智慧教育借助“互联网+”手段，提供丰富多样的学习资源，包括在线课程、教学视频、电子书籍、模拟实验等。智慧教育十分注重个性化学习，通过分析学习数据和行为，依据学生个体差异和特点提供定制化的学习内容，满足不同的学习需求。

2.1.3 学习自主性高、互动合作强

智慧教育注重培养学生的自主学习能力，通过提供自主探究学习资源和工具，激发学生的学习兴趣和学习动力。它倡导学生间互动合作，学生可以通过在线平台和社交工具，讨论、共享学习资源，促进知识共建和交流。

2.1.4 空间弹性化、灵活移动性

智能手机和移动设备的普及，为智慧教育提供了移动学习便利。智慧教育能够不受时间和空间限制，灵活安排学习时间和地点，实现弹性化学习。

2.1.5 数据驱动性

智慧教育能够依托互联网技术和大数据分析，收集、整合、分析学习数据，为教师和学生提供科学、准确的反馈和决策支持。

2.2 传统教育与智慧教育的差异

从上述人工智能背景下智慧教育的特征可以发现：传统教育和智慧教育具有一定的区别，如表1所示。

2.3 影响人工智能背景下智慧教育发展的因素

2.3.1 环境客体因素

环境客体因素包括信息技术、政府政策、法律法规以及资源共享。

（1）信息技术。信息技术的发展使人工智能技术辅助教学成为可能，元宇宙技术、智能机器人助教、物联网技术等快速推进了智慧教育发展。

（2）政府政策。国家层面不断发文，大力支持人工智能技术赋能智慧教育。国务院发布《“十四五”数字经济发展规划》[3]，要求深入推进智慧教育，推动教育数字化转型，实施“互联网+智慧教育”大平台建设专项行动，为教育行业带来新的增长点。

（3）法律法规。现有的法律法规涵盖平台数字教育资源内容、平台接入管理规范等方面，但对个人信息安全和数据安全未做明确要求，需要制定严格的安全保护措施和隐私政策来加以规范。

（4）资源共享。互联网平台打破了传统教育的时空限制，学习者能够通过在线课程、教育应用和网络图书馆等途径获取海量学习资料和教学工具，实现了教育相对公平，有效弥补了数字资源鸿沟。

2.3.2 课堂主体因素

课堂主体因素包括学生个体因素和教师教学因素，体现在平台应用能力、师生互动效果、情景体验感受、教学方法革新、使用方便快捷等方面。

（1）平台应用能力。学生和教师须具备信息平台应用能力和较高的计算机操作能力，这对于一些技术水平较低的学生或年龄较大的教师会存在学习和适应的难度。为此，教师需要接受相关培训掌握教学技术，懂得使用在线教育工具。

（2）师生互动效果。学生通过在线讨论、团队项目等形式与教师交流，营造良好的学习氛围，加强技能培养；教师采用数据分析技术实时监控学生学习情况和综合表现，通过数据画像，对学生进行精确评估并提供个性化指导。

表1 传统教育和智慧教育的区别

类别	教学环境	教学范围	教学模式	学习体验	教学资源	教学时间	教学评价	更新速度
传统教育	传统教室（线下）	依赖传统教室和教材内容，受地域限制，跨文化交流有限	采用面对面教学模式，教师是课堂的中心，学生被动接受知识	以纸质版教材为主，学生通过课堂讲解和独立阅读获取知识	主要来自教师和课本，课堂时间有限	仅限于课堂，时间有限	教学评价单一，以教师为主体	以教师和教材为主，具有一定滞后性
智慧教育	线下+线上	通过在线平台实现跨区域和跨文化学习，与全球师生进行互动合作	利用技术和平台，创造互动和个性化的学习环境，让学生主动参与学习	利用数字技术和在线资源，提供多媒体互动和实践学习，体验更丰富	利用各类电子设备获得更广泛和实时的教学资源	可随时进行学习，无时间限制	通过技术和数据分析能够了解学习差异，教学评价多元化	可实时更新，更新速度较快

(3)情景体验感受。根据学生兴趣、能力和学习风格提供个性化学习内容和教学方法，提升学生学习效果和兴趣；利用多媒体资源、在线互动和虚拟实验等手段，创造丰富多样的教学体验。

(4)教学方法革新。在线学习模式需要教师转变角色，通过在线培训、教学资源共享和教学思维碰撞等方式，不断更新教学理念和技能，确保教学质量和效果，增强教育的创新性和适应性。

(5)使用方便快捷。学生和教师可以通过在线平台在任何时间和地点开展教育活动，灵活且便捷，有效促进了教育资源共享和教学质量提升。

3 人工智能背景下"互联网+智慧教育"生态系统的构建

3.1 生态系统整体技术架构

人工智能背景下的"互联网+智慧教育"生态系统是在分析上述影响因素的基础上，基于系统理论和协调理论产生的。系统理论主要以系统为对象，研究系统整体和组成系统整体各要素之间的相互关系，从本质上说明其结构、功能、行为和动态。[4]协同理论是指内部子系统以非线性作用形式产生协同效应，使系统有序改进提升的过程。[5]因此，人工智能背景下的"互联网+智慧教育"生态系统是从系统中的信息、人、教育信息环境三要素出发，有效整合要素，让三者之间相互作用产生协同效应，促使系统有规律地运行，维持要素之间的生态平衡。即包含"虚实环境+智慧课堂+智能评价"三个维度，具备整体关联、协同演化和动态平衡特征。通过构建生态系统达到"教、学、评、管、服"系统化与一体化，最终形成人机结合的协同教育生态新系统。

人工智能背景下的"互联网+智慧教育"生态系统技术架构的设计以信息化时代为背景，以智慧教育平台为载体。具体思路以"互联网+"技术为支撑，遵循管理系统架构，建立包括设备感知层、数据算法层、网络处理层、数据应用层四个层次的智慧教育生态循环，能够形成营造人工智能教学环境、构建智慧学习空间、开展多维智能评价、进行数据过程分析和提供个性多元使用服务的完整闭环结构，从而建立起"智慧+"内在机理，从智慧教育生态底层环境、资源再到高层场景、应用，形成一个可持续、平衡的系统架构(见图1)。

3.2 生态系统的具体实现模式

3.2.1 宏观：基于人工智能设备的"虚实"生态环境

通过人工智能技术中的智能控制终端构建"虚实"生态环境，建立中控系统、传感网络系统和无线网络系统，将传感设备与信息技术连接成一个整体，使物理环境和虚拟环境共通，拓展现有物理场域的范围，从而进行精准感知和检测。比如利用网络及云计算技术铺设5G校园网后，构建出多终端协同的网络基础设施，利用物联网技术进行人脸识别、高清视频、语音采集、情感识别等，对物理世界

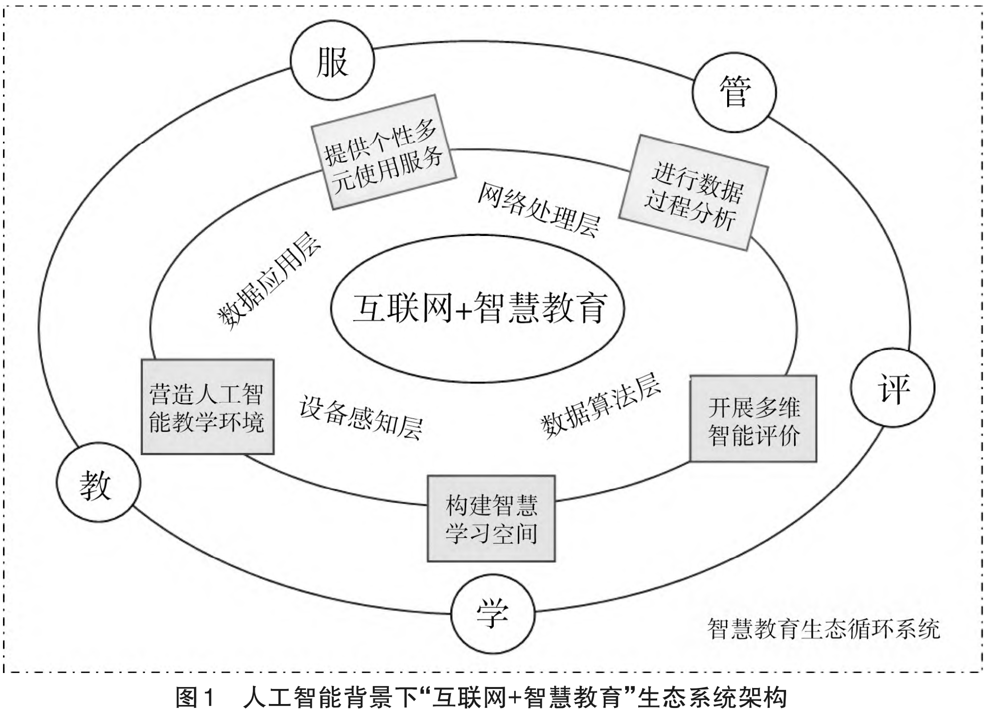

图1 人工智能背景下"互联网+智慧教育"生态系统架构

和虚拟场景进行有效链接。

3.2.2 中观：基于教师教与学生学的“智慧”生态课堂

在信息技术支撑下，学生不再被动接受知识，而是主动构建知识；教师由信息的传输者、运送者转变为学生主动构建知识的帮助者、促进者、引导者。教师利用信息技术创设现实生活中真实存在的情境，通过信息化图文声像帮助学生更好地学习知识。同时，教师在课堂教学中以问题或任务为驱动，让学生使用协作互动交流技术支持的实时录播交互系统，打破课堂时空界限，反向梳理解决问题或任务。

3.2.3 微观：基于“互联网+”的智能评价生态系统

该系统的形成依靠数据挖掘和大数据分析技术的支持。系统经过实时监控产生系列数据并对其进行二次加工后，形成学生学习和教师教学行为的数据画像，为开展智能评价提供有效依据。智能评价生态系统不但能有效提升教学和学习效果，而且能为后续的“教师教”“学生学”提供数据支撑和科学管理，有助于构建“评价标准更科学、评价形式更丰富”的智慧评价机制。

3.3 三维生态系统的优势

第一，人工智能技术的应用促进了知识资源共享，解决了传统教育中缺乏交互、个性化教育等问题，创新了教学方法，推动了教育教学改革；第二，人工智能背景下针对“互联网+智慧教育”的有益探索，可以培养学生创新性思维，提升教育信息化效能；第三，多角度构建符合“互联网+智慧教育”的教育生态新系统，能够优化教育生态流程，促进智慧教育良性和可持续发展。

4 结语

“互联网+”时代的到来为人类提供了突破时空限制、满足个性发展的数字生存环境。人工智能背景下“互联网+智慧教育”生态系统的构建为教育改革提供了一个新方向，但随着技术的不断更迭和发展，还需进一步应用和实践，为智慧教育应用提供新范式。

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Research on the Construction of the New Ecosystem of “Internet + Wisdom Education” under the Background of Artificial Intelligence

QI Shaobo, JIANG Shanshan

Abstract: Wisdom education is the product of educational informatization. Relying on “Internet +” technology to build a new educational ecosystem of “materialization, intelligence and ubiquity” has become a research hotspot in the era of artificial intelligence. Based on the background of artificial intelligence, this paper compares and analyzes the differences of teaching resources, teaching scenes, teaching evaluation and teaching management between traditional classroom and wisdom education classroom driven by artificial intelligence, and finds out the inherent laws and influencing factors of teaching and learning. Using the theory of system coordination, based on the macro, meso and micro environmental points of view, it constructs a three-dimensional new ecosystem of “virtual and real environment + wisdom classroom + intelligent evaluation”, forms a community of artificial intelligence and teaching between teachers and students, and deeply integrates artificial intelligence with the field of education and teaching, in order to speed up the development of education to a high-quality stage.

Key words: artificial intelligence; Internet + wisdom education; educational ecosystem

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一、原则：立足实践、关注权威、突出基层； 二、要求：学术前瞻、品质超群、深厚博大；
三、提倡：革故鼎新、拿来借鉴、探索争鸣； 四、欢迎：真实质朴、科学实用、真知灼见；
五、反对：陈词滥调、拼凑堆砌、繁冗拖拉； 六、杜绝：虚话假话、套话土话、抄袭剽窃。

教育元宇宙生态系统构建研究

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【内容摘要】随着 Web3.0、XR、人工智能以及 5G 技术的发展以及终身教育出现,传统职业教育领域受到冲击。当前教育领域具有单一化的特性,教学改革向大规模、数字化与智能化方向演进。元宇宙是一个集多种信息技术于一体的互联网未来新形态,引领了未来职业教育的新方向。文章以元宇宙视域下职业教育发展趋势分析为基础,创新虚实共生、跨空融合、协作探究的教育教学新模式,结合教育元宇宙当前六大支撑技术的运行机理,从物理层、数据层、软件层与应用层四个层面进行教育生态系统架构,从而打造出资源生态、互动生态、空间生态、协作生态"四生态"应用下的教育生态系统,加快元宇宙与职业教育的有机融合,构建人人皆学、处处能学、时时可学的未来职业教育学习新空间。

【关键词】元宇宙;教育教学;生态系统

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一、引言

"元宇宙"是尼尔·斯蒂芬森(Neal Stephenson)在其 1992 年的科幻小说《雪崩》(Snow Crash)中提出来的。2021 年,"元宇宙"开始走进了人们的视野,该年度被称为"元宇宙"元年[1]。元宇宙是伴随着 5G、人工智能、VR、AR、数字孪生等信息技术而产生的,创造了一个平行于真实世界的虚拟空间,能够满足人们体验式、沉浸式、共享性、创造性的需求,可以广泛应用于各个领域场景式构建。从国家层面到各地政府纷纷将此概念纳入了"十四五"发展规划,着重提出数字赋能,融合新场景,打造内容、资源、技术与服务新生态。元宇宙时代的到来为我国教育新基、学生高阶思维培养以及未来教育发展提供新机遇。

通过采用元宇宙中的数字孪生、5G、人工智能等信息技术,将教学中的教师、学习者、资源、环境等教育生态系统中相关联的变量整合在一起,发掘教育中各元素的内在规律和有机联系,构建多元化教育场景,形成统一协调教育生态新系统,使理论研究成果系统化,为教育领域与元宇宙技术的深度融合提供新思路和新方向。元宇宙技术与教育教学领域深度融合,呈现全流程化闭环结构,线上线下无边界,实现"多维"教学路径,有效弥补传统教育缺陷,营造智能、交互学习环境,实现智能驱动、个性化与高效化,因材施教,转变人才培养模式,为高质量教育教学提供新动力,具有十分重要的意义。

鉴于此,在分析元宇宙时代下教育发展趋势和教育元宇宙内涵的基础上,借助元宇宙中技术构建环境、场景、资源以及应用四个流程方面的教育元宇宙生态系统,形成虚实共生、跨空融合、协作探究的教育教学新模式,并进行资源生态、互动生态、空间生态、协作生态的具体应用,最终形成一体化、系统性、协作交互的教育生态系统。

二、教育元宇宙研究及发展现状

(一)国外研究。发达国家研究起步较早,相关研究成果较多,元宇宙相关的信息技术比较成熟,特别是在美国、德国、印度发展较为迅速。查询近十年的文献,技术层面多数为构建教育平台生态的具体技术方法和应用,理论层面主要是对元宇宙概念界定。纽约乔纳森·格里克(Jonathan Glick)认为元宇宙的发展包含初级和高级两个阶段。初级阶段主要表现在参与者在完全虚拟的空间中生存的愿望,该空间在某种程度上比现实世界更"美好";高级阶段才是最终实现事实与虚构之间联系的技术生态体(Hackl,2021)[2]。并且元宇宙已在美国教育领域有所应用,加州大学伯克利分校在沙盘游戏《我的世界》中搭建数字校园并举办线上毕业典礼。韩国教育部也启动了元宇宙创意科学教室计划。在教育研究领域,Oshima 等人探讨机器人如何作为智能导师辅助支持开展教学等[3];Rensing 教授提出了基于查询的文本学习资源推荐系统和自动生成知识库的知识推荐系统;Jennifer 等开发了基于学习者写作能力的智能写作系统。Chae Yeon Keun 提出 XR(扩展现实)在教育培训中的 IEEE 802.11 ax 优化设计(Chae Yeon Keun,2022)[4]。

(二)国内研究。我国关于教育元宇宙应用研究现状,通过对中国知网、万方数据、百度学术等知名数据库调研后发现,主要包含以下两个方面:

1.研究数量。以中国知网为例,进行"元宇宙"和"教育教学生态系统"等关键词检索,查询结果显示近十年与主题相关研究共有 335 篇。大部分学者对于元宇宙的研究和认识始于 2021 年。关于教育生态系统研究始于 2013 年,研究成果数量

呈逐年增加并快速增长的趋势。

2. 研究内容。一是元宇宙教育研究。主要是阐释元宇宙教育发展趋势。《元宇宙 + 教育: 未来虚实融生的教育发展新样态》中指出教育元宇宙将实现以现实物理世界为核心的教育元宇宙与星际文明共在的未来教育形态(李海峰等,2022) [5]。《打开教育的另一扇门——教育元宇宙的应用、挑战与展望》提出了元宇宙面临的问题与挑战,并针对教育元宇宙初期的发展从机制、技术、教学三个方面提出建议(蔡苏等,2022) [6]。二是教育生态系统理论和应用方面研究。大多数讨论的是利用信息技术影响和变革教育生态系统。《AI + 教育——智能化教育生态系统助推教育公平的实现》提出以信息化手段扩充教育资源覆盖面,通过智能化学习实现教育公平(刘畅,2020) [7]。《5G 赋能下高校线上教育生态化路径构建研究》提出 5G 赋能下构建生态化教育线上模式,提高 5G 赋能下高校线上教育生态化水平(戎会会等,2021) [8]。

综合已有的研究成果发现,在元宇宙时代下,信息技术迅速发展且更加多样化,教育生态系统应呈现出人本、智能、交互、沉浸、协同等特征,如何借助元宇宙技术打造教育新生态,助力高质量教育体系建设则是未来的研究领域与方向。

三、教育元宇宙的特征

教育元宇宙是伴随着信息技术的发展而出现的,内涵十分丰富,采用数字化、多媒体等移动方式使学习形式呈现多样化状态,打破了虚拟与现实、线上与线下、课内与课外、教与学的边界,学生能够进行个性化学习,是信息技术引领构建以学习者为中心的全新教育生态,指导教育信息化实现,回归教育本质,培养智慧型人才。

元宇宙是整合多种新技术产生的新型虚实相融的互联网应用和社会形态,是基于扩展显示技术提供沉浸式体验,基于数字孪生技术生成现实世界的镜像,基于区块链技术搭建经济体系,将虚拟世界与现实世界在经济系统、社交系统、身份系统上密切融合,并且允许每个用户进行内容生产和世界编辑。因此,教育元宇宙能够跨越时空界限,为学习者呈现多样化和功能化的知识世界,开创沉浸体验学习新模式,具有系统交互、虚实共生、泛在讨论、持久协同等特性。

(一) 创造了教师教学的真实场景。教育元宇宙打破了现有物理世界时空的界限,拓宽了传统学习空间维度,通过信息技术营造了一个虚拟网络学习空间,还原真实场景。为教师和学生赋予数字身份,使得教师和学生可以在物理世界和虚拟世界同步进行交流,互相联系,互相影响,同步发展,弥补在实际物理教学上的缺憾,呈现出完美真实的教学状态。

(二) 打造了沉浸式教学体验。构建与元宇宙虚实技术融合的学习环境,教师通过辅助设备,采用三维立体交互呈现方式将涉及教学知识点的视频和图像直观展示在元宇宙教育场景中,实现了现实与虚拟的无缝对接,让学生能够获得适宜的个性化学习服务和真实学习体验,获得视觉、听觉和触觉等多元化综合体验,实现多模态学习,产生"身临其境"的感觉。教学体验丰富、立体,激发学生学习的求知欲,提升教学的效果与质量,增强了学生学习效能。

(三) 实现了学生协作、个性化学习。教育元宇宙中可以灵活开展教学活动,根据不同学生的学习需求定制不同的学习场景。师生共同进入元宇宙,能够进行实时教学互动和智能对话,实现学生多人异地协同共同学习,开展探究讨论,实时共享信息和丰富资源,进行深度交流,促进知识内化。同时,可以修改创建新的学习资源,进行知识创造等学习活动,提供个性化学习空间,培养学生的高阶思维能力和核心素养。

(四) 促进了学科多元、全面融合。突破原有人才培养学科体系的限制,打破课程体系之间的关联,对课程体系进行多角度整合,进行跨学科教学模式实践与创新,赋予学生更大的自由度,自由进行各种教学活动。

因此,在元宇宙视域下智慧教育呈现出虚实融合、协同交互、资源共建等特性,与传统教育相比,打破时空边界,增进了具身认知和情景体验,实现了协作交互、动态化新的教育生态。

四、教育元宇宙生态系统构建

根据元宇宙的特征我们发现教育元宇宙受智慧环境、多样资源、教学场景以及教学应用四个方面影响。因此,结合生态学原理进行教育元宇宙的构建。具体构建流程如下:

教育元宇宙生态系统架构是基于生态学原理进行设计的,遵循教育生态系统定义,利用元宇宙技术进行内部和外部生态系统建设,统筹内部结构与周围环境的相互关系、相互作用和相互适应性,充分考虑教师、学生、管理人员等用户需求,进行互联互通,全过程实现与教育的深度融合,教育系统要素以及要素之间的关系得以重新建构,包括教育环境、技术等要素都重新定义,使得传统教育环境泛在化、教学资源真实化; 教师教学模式灵活化、教学手段智能化; 学生学习方式个性化、学习内容精准化。

设计流程以虚拟现实、人工智能等六大核心技术为支撑,从教师、学生、环境、技术、资源五个要素功能出发,以信息管理系统架构分层次原则为出发点,从底层的基础设施层(IaaS) 开始构建,通过使用虚拟化技术、云计算技术和云存储体系,形成沉浸式环境,实现跨层级、跨平台对接、数据共享与系统集成,从而构建系统化的资源和平台,实现教育场景搭建和应用。具体包括物理层(终端设备) 、数据层(云平台) 、软件层(交互软件) 和应用层(应用案例) 四个层级,每一层级相互关联、层层递进。最终,形成逻辑关联,从智慧教育生态底层环境、资源到高层场景、应用,形成一个可持续性、完整性、平衡性的系统架构,促进智慧教育生态系统良性循环与发展。(如图 1 所示)

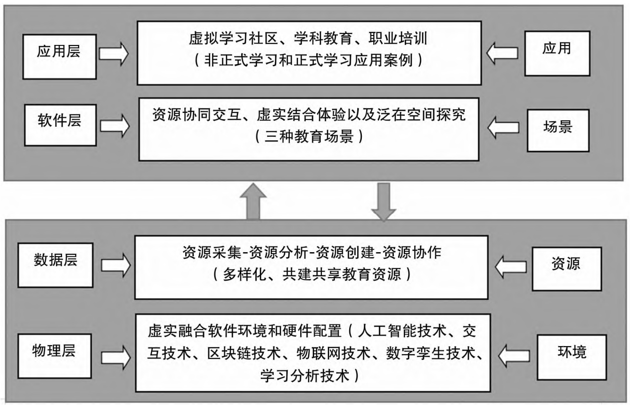

图 1　教育元宇宙生态系统

(一) 教育环境。教育环境包括软件环境和硬件配置,利用网络及运算技术铺设 5G 校园网后构建出多终端协同的云计

算网络基础设施;利用物联网技术接入元宇宙通道,进行人脸识别、高清视频、语音采集等,对物理世界和虚拟场景进行有效链接;利用区块链技术保证教学过程中产生数据的安全性和完整性,为学生和教师进行知识分享与认证提供保障;利用交互技术,为元宇宙带来无线学习空间,建立计算机图形学、多模态识别等人机交互三维立体学习环境;利用人工智能技术对教师教学行为和学生学习行为进行全方位分析和数据挖掘、进行知识图谱和多模态计算以及智能分析;利用电子游戏技术、虚拟数字场景等,让学生沉浸在教育元宇宙中学习,教师采用游戏化教学,任务驱动,优化课堂教学环境,打造人机协同双师课堂,最终建立学生成长档案进行因材施教。

(二)教育资源。教育资源包括学习资源、交互资源等。在元宇宙教育过程中利用云平台对数字资源进行采集存储,获取虚拟和现实联结数字化形式资源后加工并管理,缩小数字资源鸿沟,构建开放教育资源生态。学生和教师自由进入并进行编辑创造,实现协同资源创造和更新,打造全面、丰富以及个性化的教育资源。同时,发挥资源核心价值,进行资源的共享和配置,实现资源互通有无,师生共建资源共同体。

(三)教学场景。依据教育元宇宙交互性、沉浸式以及协同多元的特性,利用扩展现实、数字孪生等技术,建立场景交互组件,虚实无缝切换,搭建出资源协同交互、虚实结合体验以及泛在空间探究等教育场景,解决传统教育单一场景的问题。通过场景式教学,沉浸式体验,丰富学习活动形式,进行场景多元塑造,生成学生画像,满足不同学生的多种学习需求,便捷地组织学习,无障碍地进行交流,实现智能化教学评价与教师课堂分析,促进学生全面发展和教育教学质量提升。

(四)应用范围。应用范围相对比较广泛,一是学科教育应用。学生借助直观、可交互的 VR 三维场景进行语言、人文、历史、地理等学科情景学习,个性化推荐资源等。二是虚拟学习社区应用,此应用成为学科应用的第二课堂,为学生开展丰富的课外活动和实践教学环节,如参观虚拟博物馆、实验室等,建立虚拟社区开展社会活动与调查等。三是可以实现跨学科教育,进行职业培训等,不受空间的限制,提供高度仿真的实践环境,培养学生的实践能力和操作技能,强化培训中心专业技能,打破教育壁垒,支持学习成果认定与转换,建立终身教育学习系统,创造更多学习机会,进行职业培训。

五、具体教学应用——教育元宇宙生态系统场景

教育元宇宙生态场景的应用涉及资源生态、空间生态、互动生态和协作生态。

(一)资源生态:多维真实。在教育元宇宙中,教育资源是多维且真实的,资源生态应用主要采用 3D 技术对图形渲染,呈现动态画面,有效提升课程的吸引力。学生根据教师提供的资源场景,利用元宇宙中的物体可探索、工具可操控以及数据全生命周期监控等数据采集与分析的功能,进行资源在线系统进行人机交互,生成教学问题解决方案,打造丰富、全面以及个性化资源,优化资源配置,促进资源共建共享。

(二)空间生态:虚实结合。虚实结合空间生态打破了传统教育体验学习的局限性,学生可以开展自身体验、反思观察、抽象概括以及行动应用等学习活动。上课时形成虚实结合空间生态,学生通过穿戴设备以及人机交互技术进入教育元宇宙,展现出逼真学习问题画面,通过对学习问题观察,进行体验转换。同时,实现多模态学习,提供智能分析和问题结论阐述,进行再次验证反复体验。

(三)互动生态:泛在灵活。教育元宇宙中实现了现实中的学习空间与元宇宙中的学习空间功能连接,打破物理边界,学生和教师进入教育元宇宙空间,教师明确探究问题,组织课堂答题竞赛、分组讨论和游戏式练习等互动,学生利用元宇宙进行灵活性研究假设讨论,借助人机交互设备,发挥元宇宙中群体协作功能,学生根据讨论状态,可以不断地修改观察探究问题结果,同步智能反馈信息结果。教师围绕学生讨论活动结果可以提出改进方案。教师和学生之间形成互动生态。

(四)协作生态:探究改进。教育元宇宙中教师和学生之间是互相协作的,在课前和课后阶段发生。课前教师为学生创建教学问题情景、探究问题方案,建立问题假设。课后教师再次进行问题创设,进行双向反馈,学生可以改进教学问题验证问题结论完成问题探究。

六、结语

利用信息技术促进教育变革已经成为国际社会的普遍共识,随着元宇宙的逐步完善及其应用领域的不断拓展,学者开始关注并探讨元宇宙在教育领域的应用,这对于构建“人人皆学、处处能学、时时可学”的学习型社会具有重大意义。当前元宇宙的教育应用探索仍处于起步阶段,缺少成熟的理论成果,本研究立足于生态学理论,从理论角度构建元宇宙视域下教育生态系统,以期为推进元宇宙在教育领域的应用提供借鉴。

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团体沙盘游戏在高职院校艺术类大学生宿舍人际关系中的干预研究
——基于辅导员工作案例分析

□高　卉

【内容摘要】以高校辅导员在工作过程中的个案为例，通过对个案进行案例分析并提出解决举措，让有人际交往问题的宿舍6名艺术类大学生体验团体沙盘游戏，结果显示团体沙盘游戏可以再现现实中的宿舍人际冲突，增强宿舍成员之间的人际沟通能力，提升大学生的人际交往能力。

【关键词】团体沙盘游戏；高职院校；艺术类；大学生；人际关系

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《普通高等学校辅导员队伍建设规定》(教育部〔2017〕43号令)中指出辅导员是开展大学生思想政治教育的骨干力量，是高等学校学生日常思想政治教育和管理工作的组织者、实施者、指导者。辅导员应当努力成为学生成长成才的人生导师和健康生活的知心朋友。其中心理健康教育与咨询工作是辅导员的主要工作职责之一。新形势下，高校辅导员既要做好思想政治教育工作也要关注学生心理健康，因此就需要提升专业素养，运用专业的技术和方法，以理论指导实践，在实际工作中助力大学生成长成才与全面发展。大学生时期是世界观和人格发展的关键期，处于从学校走向社会的过渡阶段，这一阶段也是心理障碍的多发期。某高校心理咨询中心数据显示，在所有的咨询案例中，有70%是人际交往问题，某高校最近的心理普查结果显示，测量结果异常的同学中54%具有人际交往问题，由此可见人际交往问题已经成为影响大学生心理健康的主要问题之一。大学生的人际交往问题主要体现在宿舍人际交往问题上，宿舍是大学生学习生活、课外活动的主要场所，大学生几乎大部分时间都在宿舍。"00后"艺术类大学生性格相对张扬、受约束意识较为淡薄、作息时间较为不规律，同宿舍成员之间在性格、生活习惯、兴趣爱好、价值观等方面也存在较大差异，这一群体具有新时代特殊性，艺术类大学生宿舍经常出现人际关系紧张现象，给辅导员的学生管理工作也带来了一定困扰。因此，如何缓解这种宿舍人际关系问题，并采用合适的干预方式改善宿舍人际关系至关重要，也是高校辅导员需要深入研究的课题之一。

一、沙盘游戏

多拉·卡尔夫发展创立了心理治疗方法——沙盘游戏治疗，其是在荣格心理学原理的基础上发展起来的，这种方法起初主要用于个体治疗。个体来访者在沙盘中进行实践性和创造性的活动，可以依照自己的喜好自由选择摆件(沙具)摆放在沙箱当中，每一个沙具都是具有象征性意义的，最终形成一幅画、一个场景。沙盘作画可以让来访者自由、真实地表达自己，反映无意识的内容，有助于表达其内心的世界，呈现内心的矛盾和问题，表达来访者最真实的心理体验，作画过程中使得真实的内心世界得到投射，指导师则是给出指导后在一旁静静观察，观察来访者在作画过程中的表现，捕捉每一个细节，让来访者在自由的、受保护的空间尽情表达自己、释放自己，同时解读、分析来访者所作的图画蕴含的象征意义。游戏的过程中来访者也可以看到自己投射出来的内心世界，能够实现自我觉察，

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数字化时代提高高职院校教师数字能力的策略探讨

张艳艳 [1,2]

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摘要： 在信息技术快速发展的背景下，数字化技术在深刻地改变着社会的各个领域。数字化技术的广泛应用，推动着教育模式、教学方法以及学习体验等方面发生变革。对于高职院校而言，教师的数字能力成为影响人才培养质量的关键因素。拥有良好数字能力的教师，能够更好地将数字化工具融入教学，激发学生的学习兴趣，提升教学效果。该文深入探讨提高高职院校教师数字能力的策略，目的在于促进教师专业发展，推动高职院校数字化教学达到更高水平。

关键词： 数字化；高职院校；数字能力；专业发展；人才培养；教育教学

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Discussion on Strategies to Improve Teachers' Digital Ability in Higher Vocational Colleges in Digital Age

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Abstract: Under the background of the rapid development of information technology, digital technology has profoundly changed every field of society. The wide application of digital technology has promoted great changes in education model, teaching method and learning experience. For higher vocational colleges, teachers' digital ability has become a key factor affecting the quality of talent training. Teachers with good digital ability can better integrate digital tools into teaching, stimulate students' interest in learning, and improve teaching results. This paper discusses the strategies to improve the digital ability of teachers in higher vocational colleges in order to promote the professional development of teachers and promote the digital teaching in higher vocational colleges to a higher level.

Key words: Digitalization; Higher vocational colleges; Digital ability; Professional development; Personnel training; Education and teaching

随着第五代移动通信技术、人工智能、大数据等前沿数字技术的快速进步，数字化技术变革已成为推动各行各业发展的关键动力。教学实践持续引人数字化资源。在当前形势下，高等职业院校教师的信息化素养是影响教学质量与人才培养效果的核心要素。因此，本文研究并制定提升高职院校教师数字能力的有效措施，以期提高高等职业教育质量，培养适应数字时代需求的高素质技能人才。

1 数字化时代提高高职院校教师数字能力的重要作用

1.1 有利于提升教学质量

传统的高职院校教学模式往往较为单一，教师依托数字信息技术，能够接触丰富的教学资料库，包括高质量的教学视频、虚拟实验系统等教学资源，拓展课程知识边界。如对于工科专业课程，教师可运用三维建模软件以及虚拟现实技术，将抽象的机械构造与工艺流程以直观方式向学生呈现，使学生体验真实的生产现场氛围，极大地促进了学生的认知发展及学习效率提升[1]。教师采用数字化教学辅助技术能够实现对教学活动的精确剖析，应用数字化教学管理技术可实时掌握并全面了解学生的学业进展、作业完成情况及其对知识点理解的深度，据此对教学策略进行有针对性的优化和调整，因材施教，提升教学质量[1]。

1.2 有利于促进学生发展

在数字化技术迅速发展的背景下，学生对知识获取的效率提出了更高的要求，拥有数字能力的教师可借助网络学习资源，为学生量身定制专属的学习方案，适应学生的多样化需求。对于基础能力较弱的学生，教师能够为其提供具有针对性的基础理

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论教学视频及配套练习题；对于具备较强学习能力的学生，教师则为其提供全面的学习资源及项目实操机会，借助数字化技术培养学生的数字素养与开拓性思维，使学生具备数据分析与编程等数字化技能，为学生未来的职业发展提供坚实基础，提升他们的就业竞争力[2]。

1.3 有利于增强教师数字素养

增强数字素养是教师专业发展的核心要素之一。为了更好地发挥数字技术的作用，教师应持续优化知识结构，深入理解和熟练运用先进的教学理念与策略，研究现代教育领域中人工智能技术的应用与发展趋势，掌握机器学习、深度学习专业知识，提升教学研究能力[3]。教师应开展数字化教学交流，不断对教学实践进行反思与批判性分析，提升教学能力，从课堂知识的传授者向学生学习的引导者与推动者角色转变[4]。上述过程会促使教师的数字素养不断提升、助力其专业发展。

2 数字化技术对高职院校教师教学能力的影响

2.1 数字化技术改变教学模式

在传统的高职教育体系中，以教师讲授为主的教学模式占据主导，使学生在学习活动中被动接受知识。数字化技术催生线上线下融合、项目导向、翻转课堂等多样化的教学模式。借助学习管理系统，教师可实施线上线下混合式教学，让学生在课前通过线上教学平台自主掌握基础理论知识，课上组织学生围绕问题进行深入探讨并实施实践操作技能训练，实现了以学生为主体的教学[5]。

2.2 数字化技术丰富教学资源

数字化技术的深入应用使教学资源的获取与共享变得更为高效。高职院校教师可依托互联网技术高效获取大量优质的教学资源，包括国际及国内知名高等教育机构开设的开放性课程、专业前沿的学术研究成果以及行业最新的实践案例等[6]。这些丰富的教学资源能够增强教学内容的生动性与实际应用性，如在市场营销学科的教学活动中，教师可引入最新的电子商务营销实例，使学生全面了解行业最新发展趋势与实际操作技术[7]。

2.3 数字化技术重塑教师角色

在数字化技术快速发展的背景下，教师角色已从知识传授者向多元化教育者转变，成为学生学习的推动者与教学资源的整合者。随着学生获取知识途径的日益多样化，教师需指导学生精准筛选并合理运用信息资源库；采用数字化技术，为学生实施个性化的教学；借助学习分析技术，对学生的学习特点与需求进行精准把握，为学生实施针对性的学习辅导[8]。

3 数字化时代高职院校教师数字能力提高的路径

3.1 构建数字化教学培训体系

构建全面且结构化的数字化教师培训体系，是增强教师数字化技能的根本保障，培训课程设计应全面覆盖多个知识板块，涵盖数字技术的基本操作技能。教师需对虚拟现实软件、智能化教学辅助系统等数字教学工具的运用进行更深入的挖掘，分析数字技术背景下的教学理念与方法创新，如基于大数据技术的个性化教学策略、融合多元化教学模式的课程设计理念等[9]。高职院校可开展集中培训、工作坊及讲座等系列专业活动，便于教师面对面互动与实操；还可邀请业界专家及技术人员开展案例剖析与经验交流，确保教师掌握数字技术在教学领域的最新应用方法[10]。

3.2 建立激励机制

完善的激励机制能够充分调动教师提高数字能力的内在潜能。高职院校可设立专门的奖励制度，对在数字教学领域业绩突出的教师实施物质奖励，如奖金、教学设备购置的专项补贴等；在职务职称评审及各类奖项评选中，将教师的信息化教学水平及其数字教学成果在实践中的应用成效纳入核心评价体系，对于制作出优质数字化课程及在数字教学竞赛中表现优秀的教师给予加分，为教师的持续发展提供坚实保障[11]。高职院校可举办数字化教学成果展示活动，以展示教学创新成果，对优秀教育人才实施表彰，为教师搭建更全面的学习与交流平台，鼓励其参与国内与国际举办的数字教育研讨会议及学术交流活动，使教师拓展教学视野。

3.3 开展实践活动

教师数字能力的提高离不开教学实践的有效开展，高职院校应推动教师参与各类数字化教学活动的组织与实施，大力支持教师开展数字化教学模式创新项目。教师应将个人专长融入所授课程，研究数字技术在教学领域的应用，以优化教学内容、革新教学方法及创新教学模式。教师可采用虚拟现实技术打造沉浸式教学新形态，使学生在仿真教学环

境中掌握技能，提高学生的学习兴趣与实际操作技能[12]。高职院校应推动数字化教学实践周期活动及数字化教学实践月度活动的开展，要求全体教师将数字技术全面融入教学体系与课程设计，强化教师的数字化教学能力。高职院校应组织教师开展教学观摩与经验交流，鼓励教师相互学习。高职院校还可以进一步深化与企业的合作，构建教师企业实训平台，促进教师与企业导师共同探索教育新路径[13]。

3.4 借助技术工具创新教学方法

教师需积极掌握并熟练运用各类数字化技术工具，将其用于教学实践，拓展教育资源。教师可采集并记录学生学业成果相关数据，全面剖析学生的学习特点与个性化学习需求，为学生量身定制学习路径与学习方案。教师可采用区块链技术，强化教学评价的公正性与可靠性，全面评价学生的学业进步情况及学习成效[14]。

4 结束语

综上所述，构建数字化教学培训体系、实施激励机制、举办实践活动、强化教师团队数字化合作以及运用技术创新教学方法等多种策略的综合实施，能够显著提高高职院校教师的信息化教学与数字素养水平，构建职业教育数字化师资力量保障体系。

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检 索 报 告

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Metaverse is the future of the Internet and integrates a variety of information technologies. It leads future education trends and brings profound changes to education. On the basis of analysis of the development trend of smart education and the connotation and action mechanism of edu-metaverse in the view of metaverse, this paper structures the smart education ecosystem, builds the scenario and modular smart learning space of three education scenarios of resource collaborative interaction, virtuality-reality integration experience, and ubiquitous spatial inquiry by using the six core technologies, and forms the new education mode of virtuality-reality symbiosis, trans-spatial fusion, and collaborative inquiry. Then, it verifies the application effect by AHP. Finally, it creates the smart education ecosystem of "four ecology integration"- resource ecology, interaction ecology, space ecology, and collaboration ecology, which accelerates the organic integration of metaverse and smart education and provides theoretical basis and reference for the new application of future education.

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Recent advances in wireless technologies and battery performance have enabled increasingly more powerful mobile computing devices, that are themselves more widely available than ever before. The emergence of these devices has led to a proliferation of users engaging in data communication and processing on a massive scale. To report advances in this area, this journal publishes studies that present the theory and/or application of new ideas and concepts in the field of mobile information systems, and welcomes submissions from researchers, practitioners, and professionals across academia, government, and industry.

As well as original research, Mobile Information Systems also publishes focused review articles that examine the state of the art, identify emerging trends, and suggest future directions for developing fields.

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Building a Smart Education Ecosystem from a Metaverse Perspective

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Metaverse is the future of the Internet and integrates a variety of information technologies. It leads future education trends and brings profound changes to education. On the basis of analysis of the development trend of smart education and the connotation and action mechanism of edu-metaverse in the view of metaverse, this paper structures the smart education ecosystem, builds the scenario and modular smart learning space of three education scenarios of resource collaborative interaction, virtuality-reality integration experience, and ubiquitous spatial inquiry by using the six core technologies, and forms the new education mode of virtuality-reality symbiosis, trans-spatial fusion, and collaborative inquiry. Then, it verifies the application effect by AHP. Finally, it creates the smart education ecosystem of "four ecology integration"—resource ecology, interaction ecology, space ecology, and collaboration ecology, which accelerates the organic integration of metaverse and smart education and provides theoretical basis and reference for the new application of future education.

1. Introduction

The term "metaverse" was coined by Neal Stephenson in his 1992 science fiction novel "Snow Crash." In 2021, the "Roblox" game platform was launched, which was a landmark event and garnered widespread attention. The word "metaverse" is increasingly popular nowadays, and this year 2021 is known as the year zero of the metaverse [1]. Metaverse emerges with the development of information technologies such as 5 G, AI, VR, AR, and digital twins. Both national and local governments have incorporated this concept into the 14th Five-Year Development Plan, focusing on digital empowerment, integrating new scenarios, and creating a new ecosystem of content, resources, technology, and services. As the metaverse era unfolds, new opportunities open up for new infrastructure of Chinese education, cultivation of advanced thinking among students, and future educational development. At present, "metaverse" has not yet been uniformly defined. There are four main theories: embodied Internet, social ecology, virtual space and time, and virtuality-reality combination. Thus, this study believes that metaverse is a virtual space parallel to the real world and IS supported by AI, big data, HCI, and other communication technologies, which can meet people's experiential, immersive, sharing and creative needs and can be widely applied in various fields.

The concept of educational ecology integrates pedagogy and ecology. It is an interdisciplinary subject that emerged in the mid-1970s [2–5]. It mainly studies the laws and mechanisms of how education interacts with its surrounding environment, opening up a new field in education studies. From both macro and micro perspectives, educational ecology borrows the principles and methods from ecology to study the process, law, and ecological balance of the interaction between education and information, people, and the environment so as to leverage educational resources to improve students' cognitive ability and improve the level and function of the entire ecosystem, allowing it to enter a virtuous cycle.

Educational ecology has three basic characteristics: overall association, coevolution, and dynamic balance [6]. The smart education ecosystem is also built on the above basic theories. The concept of smart education originated in

2008 when IBM first proposed the concept "Smarter Planet" in *A Smarter Planet: The Next Leadership Agenda* [7]. The concept later spread to various fields and inspired new ideas, leading to the emergence of smart education. The core of smart education is to enable the perception, interconnection and intelligence of everything through the use of information technology. With the development of intelligent technology, especially 5 G technology, China has issued a package of policies to reform its education model and accelerate the development of smart education [8]. To sum up, smart education ecosystem is a "symbiotic, dynamic, balanced, and sustainable" system that integrates the effects, interconnection, and educational elements. It organically connects educational subjects (teachers and students) with educational concept, teaching design, teaching resources, teaching evaluation, and other factors using information technologies, aiming to realize intelligent and ecological education.

With the emergence of the metaverse, information technologies and artificial intelligence have stimulated innovation in education, transformed traditional pedagogical concepts and methods, and formed the basis for smart education. Smart education, driven by the metaverse, has become one of the most heated topics in the current educational research. Leveraging information technologies such as digital twins, 5 G, and artificial intelligence in the metaverse, smart education integrates variables in the education ecosystem such as teachers, learners, resources, and teaching environment and explores the intrinsic nature of each element. It helps to create diversified education scenarios, form a new system of unified and coordinated smart education ecosystem, systematize theoretical research results, and provide new ideas for deeply integrating education and metaverse. By applying the metaverse technology in education, a full-process closed-loop structure can be developed. With no boundaries between online and offline settings, a "multidimensional" teaching approach can be delivered, which effectively overcomes shortcomings of traditional education, creates an intelligent and interactive learning environment, and realizes intelligence-driven and customized education. This new pattern is of great significance for improving educational quality and efficiency, delivering tailor-made education, transforming education modes, and providing new impetus for the development of teaching and learning.

Based on an analysis of the development trend of smart education and the mechanism of education metaverse, this study creates a smart education ecosystem. Using six core technologies, we develop three scenarios, namely, resource orchestration and interaction scenario, virtual-reality combination scenario, and ubiquitous space inquiry scenario and build three scenario-based modular smart learning spaces so as to form a new education mode featured by virtuality-reality symbiosis, trans-spatial fusion, and collaborative inquiry. Then, the application value of the mode is verified using the analytic hierarchy process (AHP). Finally, a smart education ecosystem that integrates four ecologies, namely, resource ecology, interaction ecology, space ecology, and collaboration ecology, are established.

2. Current Research Status

Metaverse-related research started early in developed countries, and many results have been achieved. A number of countries, including the United States, Germany, and India, have developed relatively mature metaverse-related information technology. Based on a review of literature over the past decade, we found that at the technical level, the study of smart education mostly focused on specific technical methods and applications of the smart education platform; the most relevant theoretical aspect was the definition of metaverse. Jonathan Glick, senior editor of the New York Times, believes that the development of metaverse involves two stages. The primary stage is manifested by the desire of participants to live in a completely virtual space. They believe virtuality is somewhat "better" than the real world. The higher stage is the technical ecosystem that ultimately realizes the connection between facts and fictions [9–11]. Metaverse has been used in education in the US, where the University of California, Berkeley held an online graduation ceremony on its Minecraft digital campus. The South Korean Ministry of Education launched a metaverse-based creative science classroom program. In smart education research, Oshima discussed how robots can assist in teaching as intelligent mentors [12]. Professor Rensing proposed a query-based recommendation system of text learning resources and a knowledge recommendation system that automatically generates knowledge bases. Jennifer et al. developed an intelligent writing system based on learners' writing ability [13]. Chae presented IEEE 802.11 ax Optimal Design for XR (Extended Reality) in Education and Training [14]. We reviewed research on the application of metaverse-based smart education in China from well-known databases such as CNKI, Wanfang Data, and Baidu Xueshu, and found as follows: (1) *The Number of Studies.* Taking CNKI as an example, using keywords such as "metaverse," "education ecosystem," and "smart education," 335 relevant papers were published in the past decade. Most scholars began studying metaverse in 2021 and smart education ecosystem in 2013, with research results increasing year by year. (2) *Research Content.* In terms of metaverse education, previous research mainly explained the development trend of metaverse smart education. *Invitation to Metaverse: A Discussion on the Need of a New Space for Future Education* described the potential of the metaverse for educational development in the virtual world [15]. *Metaverse and Education: A New State of Educational Development in the Future* believed that the edu-metaverse will lead to a future education form that combines the edu-metaverse with the physical world as the core of the interstellar civilization [16]. In *Open Another Door of Education—the Application, Challenges and Prospects of Edu-metaverse*, the authors presented the problems and challenges facing the metaverse and propose solutions for the early development of edu-metaverse from mechanism, technology, and teaching [17]. In terms of smart education and ecosystem theory and application, past studies mainly discussed the applications of "Internet +" in smart education, which uses information technologies to influence and transform the education ecosystem. *AI + Education—Smart Education Ecosystem Boosts the Realization of Educational Equity* proposed to enhance the availability of educational resources through information-based methods and realize educational equity through smart learning [18–21]. *Research on the Construction of Ecological Path of Online Education in Universities under 5 G* proposes to develop online education with the support of 5 G and improve the ecosystem of online education in universities with 5 G [22].

Various research results suggest that in the era of metaverse, information technologies have developed rapidly and become more diverse, and the smart education ecosystem is humanistic, intelligent, interactive, immersive, and collaborative. The future research direction is to develop a new smart education ecology using metaverse technology.

3. Smart Education Trends in the View of Metaverse

As information technologies develop, smart education emerged and has transformed traditional education profoundly. The use of digital multimedia and other mobile methods leads to diverse learning forms, allowing students to customize their learning pattern. Technologies create a learner-centered educational ecology, digitalize education, and facilitate the cultivation of intelligent talents. Smart education can be seen as a new form of education amid informatization, an advanced development stage of digital education, and a ubiquitous educational information ecosystem.

With the emergence of metaverse technology, smart education presents new trends and views while driving digital transformation and intelligent upgrading. The *Metaverse Development Report* pointed out that the metaverse integrates virtual Internet application and real social forms generated by a variety of new technologies. It provides immersive experience using extended display technology, generates mirrors of the real world using the digital twin technology, and builds an economic system using the blockchain technology. It closely integrates the virtual and real worlds in terms of the economic system, social system, and identification system and allows users to produce content and edit the world [23, 24].

3.1. Simulating the Real Teaching Scenario. With information technologies, it breaks down the boundaries of space and time in the physical world, expands the traditional learning space, and creates a virtual learning space that simulates the real settings. It gives teachers and students digital identities, allowing them to communicate synchronously in both the physical and virtual worlds. Students and teachers interact and influence each other and develop together, making up for the shortcomings of physical teaching and demonstrating a better teaching pattern.

3.2. Creating Immersive Teaching Experience. In a metaverse-based learning scenario, teachers can adopt highly effective teaching methods and directly and intuitively display videos and images related to the teaching content. Reality and virtuality are seamlessly connected so that students can customize learning services and enjoy real-life learning experiences. Through auxiliary equipment, a three-dimensional interactive presentation method can be employed to produce diversified and comprehensive sensational experience such as vision, hearing and touch, realize multimodal learning and to create a sense of "being there." Rich and 3D teaching experiences stimulate students' curiosity, enhance the teaching effect and quality, and improve learning efficiency.

3.3. Facilitating Students' Cooperation and Personalized Learning. Flexible teaching activities can be carried out by teachers. In the metaverse, teachers customize learning scenarios to cater to the needs of students. Teachers and students interact in the metaverse in real time, and students are allowed to collaborate on learning in different places. Thorough inquiry and discussion, sharing of information and resources in real time, as well as in-depth communication, students can better absorb and internalize knowledge. Teachers can also modify and introduce new learning resources for learning activities to create personalized learning space and enhance students' thinking abilities and literacy level.

3.4. Promoting Interdisciplinary Studies. Smart education transcends the single medium and linear teaching process of traditional teaching, addresses the limits of the original talent training system, breaks down the correlation between curriculum systems, facilitates STEM education as well as interdisciplinary teaching and innovation, and gives students greater freedom to engage in various forms of teaching.

Therefore, in the era of metaverse, smart education is characterized by virtuality-reality integration, collaborative interaction, and resource coconstruction. Compared with traditional education, it breaks down the boundaries of time and space, enhances students' cognition and scenario-based experience, and creates a collaborative, interactive, and dynamic education ecology.

4. Construction of the Metaverse-Based Smart Education Ecosystem

4.1. Ecosystem Architecture. The architecture of the smart education ecosystem is designed on the basis of metaverse-empowered education and ecological principles. Following the definition of smart education ecosystem, the metaverse technology is used to build internal and external ecosystems and to coordinate the internal structure, interaction, and mutual adaptability with the surrounding environment. The ecosystem fully considers the needs of teachers, students, administrators, and other users. It incorporates smart education into the whole process of education and integrates the elements of the smart education system and other elements, reconstructing the relationship between the elements, including the smart education environment and

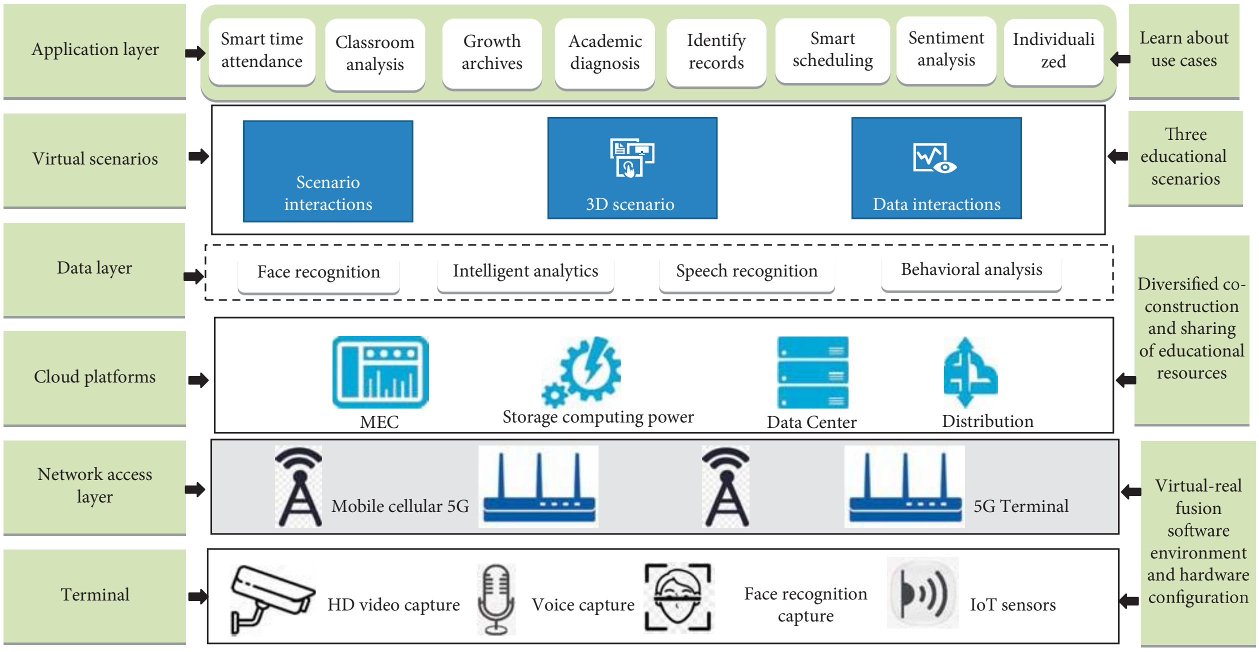

Figure 1: Architecture of the smart education ecosystem in view of metaverse.

technologies. It transforms the traditional educational environment into a ubiquitous one and adopts real teaching resources, flexible teaching modes, and intelligent teaching methods. The students' learning methods are personalized, and the learning content is targeted.

The design idea is supported by six core technologies including virtual reality and artificial intelligence, including the five elements of smart education, teachers, students, environment, technology, and resources. The foundation is the hierarchical principle of information management system architecture. First, the infrastructure layer (IaaS) is constructed. By using virtualization, cloud computing, and cloud storage technologies, an immersive environment is formed to realize cross-level, cross-platform docking, data sharing, and system integration so as to integrate systematic resources and platforms and develop and apply education scenarios. Specifically, the ecosystem has four layers: physical layer (terminal devices), network layer (cloud platforms), data layer, and application layer. The layers are interconnected and developed progressively. Eventually, a logical connection is formed between the underlying environment, resources of the smart education ecosystem, and the high-level scenarios and applications. A sustainable, complete, and balanced system architecture is then created to promote the virtuous circle and for the development of the smart education ecosystem [25–30]. (See Figure 1).

4.1.1. Environment. The metaverse-based smart education environment includes both software and hardware. By setting up hardware and software equipment in the terminal, an environment for implementing metaverse education with an organic brain-computer interface is created. After building the 5G campus network using network and computing technologies, the network infrastructure for multiterminal collaborative cloud computing is built. By accessing the metaverse channel via the Internet of Things, face recognition, high-definition video, and voice acquisition are enabled, effectively linking the physical world with virtual scenarios. Blockchain technology is applied to ensure the security and integrity of data generated in the teaching process, providing guarantee for knowledge sharing and certification. Interactive technology is used to create a wireless learning space in the metaverse and establish a 3D human-computer interaction learning environment based on computer graphics and multimodal recognition. AI technology is leveraged to analyze teaching and learning behaviors as well as data mining, knowledge mapping, multimodal computing, and intelligent analysis. With video game technology and virtual scenarios, students are immersed in the edu-metaverse. Teachers adopt game-based and task-driven teaching methods to optimize interactions, creating a man-machine coordinated classroom. Finally, growth files of students are kept to ensure tailor-made education.

4.1.2. Resources. Resources include learning resources and interactive resources. As part of metaverse education, cloud platforms are used to collect and store digital resources and also process and manage the resources that link virtuality and reality, thus narrowing the digital resource gap and building an open ecosystem of education resources. In addition, students and teachers can freely enter the edu-metaverse to edit or create content. Through collaborative creation and updating, comprehensive, rich, and personalized educational resources can be gathered. At the same time, sharing and allocation of the resources will be promoted to reduce information asymmetry and foster a community of resources available to teachers and students.

4.1.3. Scenarios. According to the interactive, immersive,-collaborative, and diverse characteristics of smart education in the view of metaverse, we establish interactions and realize seamless switch between scenarios using XR, digital twin, and other technologies. We create three education scenarios, namely, resource collaborative interaction, virtuality-reality integration experience, and ubiquitous spatial inquiry scenarios, to replace traditional teaching settings. Scenario-based teaching and immersive experience can enrich learning activities. Through shaping diverse scenarios and generating student portraits, various learning needs of students can be satisfied. Convenient learning and barrier-free communication then lead to smart teaching evaluation and classroom analysis, promoting students' all-round development and enhancing education quality.

4.1.4. Applications. The metaverse-based smart education ecosystem has wide applications. The first one is the education of specific subjects. With the help of intuitive and interactive VR 3D scenarios, students can learn various subjects such as language, humanities, history, and geography and access-recommended personalized resources. The second is virtual learning community. The community can serve as the second classroom where students carry out rich extracurricular activities, such as visiting virtual museums and laboratories and conducting social survey in virtual communities. The last application is interdisciplinary education and vocational training. A highly simulated practical environment not limited by time and space can be created to cultivate students' hands-on abilities and skills, strengthen occupational skills, break down education barriers, and support the recognition and transformation of learning outcomes. A lifelong education system can be established, and more learning opportunities are created for vocational training.

4.2. Scenarios of Metaverse-Based Smart Education Ecosystem. According to the trend analysis and architecture design of metaverse-based smart education ecosystem, we build three education scenarios of resource collaborative interaction, virtuality-reality integration experience, and ubiquitous spatial inquiry [31–33]. The process is as follows.

4.2.1. Resource Collaborative Interaction Scenario. In the resource collaborative interaction scenario, learning theory is used to design the interaction between course teaching resources and learning resources. The scenario usually occurs before and after class. In traditional teaching, teachers provide students with multimedia resources such as text, pictures, and videos. It is challenging to support students to conduct in-depth and exploratory learning as the resources lack interactivity, operability, and accuracy. In the edu-metaverse, the adopted smart education resources are multidimensional and real. For example, 3D technology is applied to render graphics, present dynamic pictures, and enhance the attractiveness of courses to students. In addition, from the resource scenarios, students can collect and analyze data, explore objects in the metaverse, use tools, and leverage the full-life-cycle data monitoring function. Users can interact with the computer via the online resource system to acquire solutions to teaching problems. The scenario integrates rich, comprehensive, and personalized resources, optimizes resource allocation, and promotes resource codevelopment and sharing.

4.2.2. Virtuality-Reality Integration Experience Scenario. Through the virtuality-reality integration experience scenario, students learn through experience, reflection and observation, abstract investigation, and application while being free from the limitations of traditional teaching practices. This scenario is used in class, where students enter the edu-metaverse through wearable devices and human-computer interaction technology. Students engage in multimodal and immersive learning by observing and experiencing. The metaverse provides intelligent analysis, explanations, and conclusions, and students can go through the content repeatedly in the system.

4.2.3. Ubiquitous Spatial Inquiry Scenario. The ubiquitous spatial inquiry scenario combines the real and metaverse learning spaces by breaking down the physical boundaries. Students and teachers enter the edu-metaverse together, where teachers create problem scenarios before class for students to explore the answers and develop hypotheses. In class, teachers put forward the problems to be inquired again, and engage students through organizing interactive activities such as classroom competitions, group discussions, and game-based exercises. Students have free discussions via the metaverse and leverage human-computer interactive equipment to collaborate with each other. Students may keep improving the discussion results, which will be simultaneously reported back to the teachers. Then, teachers put forward improved solutions based on the discussion results. After class, teachers propose new questions. Through two-way feedback, students can verify conclusions and finish learning in a scenario that combines virtuality and reality.

4.3. Applications of Metaverse-Based Smart Education Ecosystem

4.3.1. Evaluation Indicator. The final objective of the smart education ecosystem is to promote intelligent education. It focuses on three key elements, namely, learners, learning design and implementation, and learning effects. Based on the above-mentioned scenarios and characteristics, a model is constructed for scientific and objective evaluation. With the support of the metaverse technology, a smart learning ecosystem with interactive resources, and an intelligent learning environment that combines virtuality and reality, a smart inquiry space will be created. The identities of teachers, students, and schools can be transformed. Students' intelligent learning will be promoted through immersive, experiential, and self-conscious teaching

Table 1: Evaluation indicator system of the metaverse-based smart education ecosystem.

Dimension	Evaluation indicator	Evaluation criterion
Resource ecology construction	Teachers' digital literacy	Can use effective resources collected according to the characteristics of students and provide digital resources for specific learning scenarios to make learning experience more real
	Students' access to information resources	Can edit and share resources via the edu-metaverse
	School resource management	Can effectively manage learning resources and share and disseminate learning resources
Virtual and real symbiotic environment	Creation of virtual and real environments	Can establish virtual and real teaching environments as well as learning spaces with emotional interactions as the core educational content
	Organization of knowledge creation	Can remodel collaborative learning, promote self-learning, and complete teaching objectives in this process
	Emotional engagement in learning	Students can be immersed in learning scenarios by observing and experiencing; can create an immersive experience of teaching and learning
Inquiry learning space	Cooperation and sharing	Can use learning resources for communication and cooperation, and use creative tools for collaborative inquiry learning
	Learning personality portrait	Can perform intelligent data analysis and draw personalized student portraits according to students' learning behaviors and to customize teaching methods

methods. The ecosystem will cultivate intelligent and innovative students, form a new education ecology that highlights students' core competencies, and empower deeper development of smart education. Therefore, the evaluation of the metaverse-based smart education ecosystem should be dynamic and scientific. The factors that affect the smart education ecosystem and the relationship between the factors are to be evaluated and generally applied to the abovementioned three scenarios.

Based on the above analysis, this study establishes an evaluation system for the smart evaluation system from three dimensions, i.e., resource ecology construction, virtual and real symbiotic environment, and inquiry learning space. (See Table 1).

4.3.2. Application Effect of Metaverse-Based Smart Education Ecosystem. The effect evaluation is to develop an evaluation system based on the above evaluation indicator and then make a relatively objective evaluation of the effect of the smart education ecosystem. The analytic hierarchy process (AHP) method is adopted. It is a quantitative evaluation of the comparative importance of hierarchical elements according to the subjective judgmental structure of a certain object. AHP is a hierarchical weight decision analysis method proposed by Thomas L. Saaty, an American professor at the University of Pittsburgh in the early 1970s [34]. AHP uses matrix eigenvalues and eigenvector operations to help people make group judgments to determine the assignment of certain qualitative variables. It is a systematic and hierarchical analysis method that decomposes the elements related to decision into the objective layer, criterion layer, and plan layer for qualitative and quantitative analysis. This flexible method can simplify complex problems and provide a scientific basis for selecting the optimal solution and is widely used in evaluation. Since the evaluation of the smart education ecosystem involves many interconnected elements, which cannot be quantitatively expressed by data, it is rather complicated and fuzzy. Therefore, the AHP approach is used to establish a model to realize multifactor comprehensive evaluation, as well as systematic analysis of the decision-making process. It follows the general laws of educational evaluation, conforms to the characteristics and requirements of metaverse-based smart education, and is relatively scientific and applicable.

In general, the evaluation has four steps. First is data acquisition. To avoid subjective influence of the AHP method, a total of 156 teachers are selected for the survey, including teaching management officials, discipline leaders, and ordinary teachers from 21 universities and junior colleges in Henan Province. The Likert 5-level scale is adopted, and the results of each indicator are weighted and averaged and then rounded to form a matrix for evaluation. The scale mainly adopts Likert 5-level measurement method, which is relatively easy to design and can be widely applied to multidimensional complex problems or attitudes. The three scenarios of intelligent education ecosystem from the perspective of the metauniverse are suitable for this method, and each respondent can quickly mark his or her own views with high reliability. After the evaluation of the survey object, the results of each index data survey are weighted average and rounded to form a judgment matrix. Second is the identification of evaluation indicators. Based on the authors' teaching experience and previous research, three dimensions of eight indicators are identified. Third is the establishment of a hierarchy. The evaluation system is broken down into a hierarchical evaluation model. The multiobjective decision-making problem is regarded as a system of three goals (criteria), namely, resource ecology construction, virtual and real symbiotic environment, and inquiry learning space, according to the features of the smart education ecosystem. The three goals (criteria) are then decomposed into eight indicators, namely, teachers' digital literacy, students' access to information resources, school resource management, creation of virtual and real environments, organization of knowledge creation, emotional

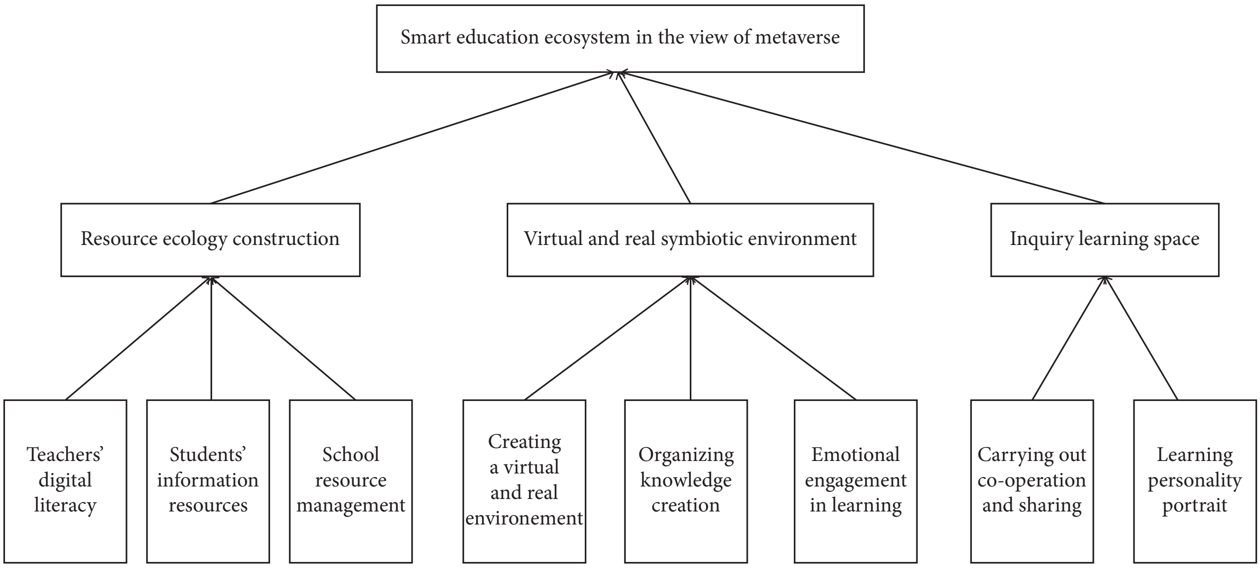

Figure 2: Evaluation system for the metaverse-based smart education ecosystem.

Table 2: Weight of the indicators for the metaverse-based smart education ecosystem.

Smart education ecosystem	Teachers' digital literacy	Students' access to information resources	School resource management	Creation of virtual and real environments	Organization of knowledge creation	Emotional engagement in learning	Cooperation and sharing	Learning personality portrait	Wi
Teachers' digital literacy	1	1/2	1/3						0.0377
Students' access to information resources	2	1	1/3						0.0599
School resource management	3	3	1						0.1426
Creation of virtual and real environments				1	5	3			0.3446
Organization of knowledge creation				1/5	1	1/4			0.0515
Emotional engagement in learning				1/3	4	1			0.1538
Cooperation and sharing							1	2	0.1399
Learning personality portrait							1/2	1	0.0699

engagement in learning, cooperation and sharing, and learning personality portrait. Then, a multilevel and orderly progressive structure evaluation structure model is developed (see Figure 2). Fourth is data analysis and conclusions. The relative importance of each influencing factor of the evaluation indicators is determined by comparing every two indicators, and an evaluation matrix is established. The overall ranking of the indicators is identified, and a consistency test is performed.

Finally, the consistency test is conducted using professional software. The specific test data are as follows: the judgment matrix is constructed according to the evaluation indicator system in Table 1. The Yaahp software is used to obtain the weights of each evaluation indicator (see Table 2). The judgment matrix passes the consistency test, with a CR value of 0.0176. The first-level indicator matrix is $\begin{bmatrix} 1 & 1/2 & 1 \\ 2 & 1 & 3 \\ 1 & 1/3 & 1 \end{bmatrix}$.

The weight indicators are 0.2402, 0.5499, and 0.2098. As can be seen from Table 2, the weight ratio of resource ecology construction, virtual and real symbiotic environment, and inquiry learning space to the smart education ecosystem is 0.2402, 0.5499, and 0.2098, respectively. The influence of virtual and real symbiotic environment is higher than that of the resource ecology construction and inquiry learning space. The weight ratios of the eight specific indicators (teachers' digital literacy, students' access to information resources, school resource management, creation of virtual and real environments, organization of knowledge creation, emotional engagement in learning, cooperation and sharing, and learning personality portrait) are 0.0377, 0.0599, 0.1426, 0.34446, 0.0515, 0.1538, 0.1399, and 0.0699, respectively.

Therefore, first, it can be seen that for the smart education ecosystem, the most important evaluation indicator is the creation of the virtual and real environments. Building infrastructure for the metaverse teaching space is the main task of metaverse teaching. Second, emotional engagement in learning, school resource management, and cooperation and sharing are the next three important indicators. On the one hand, students need to be fully immersed in the virtual environment during learning, and they must learn to cooperate and share in the learning process. On the other hand, schools should improve the codevelopment and sharing of resources so that students can be more active and innovative in the classroom and turn from knowledge consumers to knowledge creators. Last but not the least, learning personality portrait, students' access to information resources, organization of knowledge creation, and teachers' digital literacy are less important in the evaluation. Through analysis and verification, it is proven that the metaverse-based smart education ecosystem changes the traditional way of learning. The teaching activities are student-centered and highlight in-depth immersive experience as well as dynamic interaction and collaboration. Students create knowledge in collaboration and sharing and verify hypotheses and put knowledge into practice after reflection and observation. The process can help students better achieve learning objectives [35, 36]. Thus, the metaverse-based smart education ecosystem is relatively reasonable, scientific, and effective.

5. Conclusion

Using information technologies to promote educational reform has become a consensus for the international community. As the metaverse is gradually developing and its applications are expanding, researchers pay more attention to it and explore its application potential in education for building a learning-oriented society where "everyone can learn things at anytime, anywhere." At present, relevant research is still in its infancy with well-developed theoretical results. Based on the ecological theory, this study discusses the development of a metaverse-based smart education ecosystem in the hope to provide reference for promoting the applications of the metaverse in education.

The metaverse-based smart education ecosystem is student-centered and delivers dynamic and integrated teaching experience by building various education scenarios. With smart computing, it reconstructs the classroom design and realizes in-depth learning and feedback. It further enriches smart education, builds an ecosystem of teaching and learning resources, extends the educational space, and provides the functions of social communication and inquiry learning, thus effectively promoting deep interactions between learners and improving the in-depth learning of learners. The ecosystem balances the ecological niches of students, teachers, society, and schools and forms a new systematic ecosystem and is thus the future direction of smart education reform. However, the system also has certain limitations. The data flow-driven technologies still need to be improved. Real-time acquisition and processing of interactive data between the virtual and physical worlds propose challenges for the computation. The information security of students, teachers, and other users cannot be fully guaranteed, and there is a risk of personal privacy leakage. As students spend most of their time in the virtual world, those with poor self-control ability may develop social phobia, cannot properly handle interpersonal relationships, and cannot adapt to the real world. Besides, anonymous login may induce problems and violations. In terms of the evaluation effect, this paper adopts the analytic hierarchy process and Likert 5-level measurement method. The selection of experts is subjective. Although it can express the attitude of experts, it cannot describe the structural differences between viewpoints by uniformly using equal weights to calculate the weights of indicators at all levels. In future research, different weights can be given to experts according to their positions, working years, and education background, and then the weights of indicators at all levels can be calculated to make them more objective. With the continuous development of new technology, the human society is developing towards the trend of new type, science and technology, diversity, and prosperity. We also need plenty of practice for further application and exploration, constantly set up reasonable and conform to the yuan universe teaching ecological scene, combined with the characteristics of the new technology, especially virtual-reality interaction, etc., which helps to realize the organic unity, virtual and reality, and to meet the needs of wisdom education comprehensive, integrated into the teaching of each link, and strengthen the appeal and effectiveness of the science and education integration. We should optimize the ecosystem evaluation indicators and promote the synchronous development of the "meta-universe + education" related management system and laws and regulations, so as to further extend the scope of application and have universal promotion value and significance.

With the continuous development of new technologies, a large number of new applications need to be explored. There is still a long way to go to fully realize the metaverse-based smart education ecosystem. Facing more opportunities and challenges, we will gradually promote the innovative, benign, and sustainable development of the metaverse-based smart education ecology.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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摘要: PurposeThis study aims to offer a comprehensive exploration of the potential and challenges associated with sensor fusion-based virtual reality (VR) applications in the context of enhanced physical training. The main objective is to identify key advancements in sensor fusion technology, evaluate its application in VR systems and understand its impact on physical training.Design/methodology/approachThe research initiates by providing context to the physical training environment in today's technology-driven world, followed by an in-depth overview of VR. This overview includes a concise discussion on the advancements in sensor fusion technology and its application in VR systems for physical training. A systematic review of literature then follows, examining VR's application in various facets of physical training: from exercise, skill development and technique enhancement to injury prevention, rehabilitation and psychological preparation.FindingsSensor fusion-based VR presents tangible advantages in the sphere of physical training, offering immersive experiences that could redefine traditional training methodologies. While the advantages are evident in domains such as exercise optimization, skill acquisition and mental preparation, challenges persist. The current research suggests there is a need for further studies to address these limitations to fully harness VR's potential in physical training.Originality/valueThe integration of sensor fusion technology with VR in the domain of physical training remains a rapidly evolving field. Highlighting the advancements and challenges, this review makes a significant contribution by addressing gaps in knowledge and offering directions for future research.

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Sensor fusion-based virtual reality for enhanced physical training

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Abstract

Purpose – This study aims to offer a comprehensive exploration of the potential and challenges associated with sensor fusion-based virtual reality (VR) applications in the context of enhanced physical training. The main objective is to identify key advancements in sensor fusion technology, evaluate its application in VR systems and understand its impact on physical training.

Design/methodology/approach – The research initiates by providing context to the physical training environment in today's technology-driven world, followed by an in-depth overview of VR. This overview includes a concise discussion on the advancements in sensor fusion technology and its application in VR systems for physical training. A systematic review of literature then follows, examining VR's application in various facets of physical training: from exercise, skill development and technique enhancement to injury prevention, rehabilitation and psychological preparation.

Findings – Sensor fusion-based VR presents tangible advantages in the sphere of physical training, offering immersive experiences that could redefine traditional training methodologies. While the advantages are evident in domains such as exercise optimization, skill acquisition and mental preparation, challenges persist. The current research suggests there is a need for further studies to address these limitations to fully harness VR's potential in physical training.

Originality/value – The integration of sensor fusion technology with VR in the domain of physical training remains a rapidly evolving field. Highlighting the advancements and challenges, this review makes a significant contribution by addressing gaps in knowledge and offering directions for future research.

Keywords Virtual reality, Sensor fusion, Injury prevention, Mental training

Paper type Research paper

1. Introduction

Physical training has gained significant prominence in contemporary society, as an increasing number of individuals acknowledge the benefits of maintaining a healthy and active lifestyle. Numerous studies have demonstrated that physical training can mitigate the symptoms of chronic diseases, such as heart disease, hypertension, diabetes and obesity (Coats *et al.*, 1990; Diaz and Shimbo, 2013; Zinman *et al.*, 2003; Krotkiewski *et al.*, 1979). Besides physical health advantages, physical training has also been shown to enhance mental health, productivity and overall quality of life (Folkins and Sime, 1981; Sjøgaard *et al.*, 2016; Gill *et al.*, 2013). It can be conducted individually or in small groups, targeting specific personal goals such as increasing muscle strength, improving cardiovascular health, enhancing flexibility or augmenting endurance (Myers, 2003; Lam *et al.*, 2018). Historically, the evolution of technologies in the domain of physical training has been marked by significant transitions. From rudimentary tools like weights and calisthenics, there was a shift toward tools like heart rate monitors and pedometers in the 20th

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century (Epstein et al., 1985; Tapia et al., 2007; Bravata et al., 2007). With the advent of the technological era, wearable devices and mobile applications became prominent (Qi and Aliverti, 2019). Yet, the most transformative phase in this evolution has been the convergence of sensor fusion technology with virtual reality (VR), which holds the promise of redefining training methodologies across diverse domains (Ali et al., 2017). This technological integration has the potential to bridge gaps in traditional training, thereby underscoring the significance of this review.

VR, initially proposed by Jaron Lanier, is a technology that generates a sense of immersion in a computer-rendered, interactive 3D environment by using computer graphics systems and various interface devices for input and control (Mantovani et al., 2003; Gandhi and Patel, 2018). Users can interact with VR through a range of devices, such as head-mounted displays (HMDs) and motion sensors (Colaço et al., 2013). VR can be classified according to its level of immersion, which pertains to the degree of sensory engagement and human–computer interaction (Bowman and McMahan, 2007). Based on this criterion, VR can be divided into three main categories: fully immersive VR, semi-immersive VR and nonimmersive VR (Kyriakou et al., 2017). Notably, the distinction in VR classifications has relevance on a global scale. Different regions with varying infrastructural and technological advancements might find one form of VR more accessible than another (Li and Wong, 2021). Another prevalent classification of VR is grounded in hardware and equipment. Immersive VR systems typically necessitate specialized hardware, such as HMDs and data gloves, to facilitate a fully immersive experience for the user (Lantz, 1996). In contrast, nonimmersive VR generally uses a desktop computer or mobile device with a standard monitor or display to simulate a virtual environment (Saposnik et al., 2016). Significantly, sensor fusion-based VR has emerged as a pivotal advancement. By integrating data from diverse sensors, it offers enhanced immersive experiences, especially vital for physical training (Shi et al., 2023a, 2023b; Pfeiffer, 2008; Tian et al., 2023).

Sensor fusion-based VR technology has witnessed rapid advancements in recent years, finding applications across various domains such as entertainment, education and health care (Pillai and Mathew, 2019; Hsieh and Lee, 2018). In the entertainment sector, sensor fusion-based VR has been used for gaming and cinematic experiences, offering users a more immersive and interactive environment Lin (2017). Within education, it facilitates interactive and immersive learning experiences, particularly for subjects like science and history (Helsel, 1992; Wickens, 1992). In health care, it has been used for medical training and rehabilitation exercises, enabling more accurate and personalized treatment plans (Fertleman et al., 2018; Bracq et al., 2019). Moreover, in sports and physical training, sensor fusion-based VR can enhance athletic performance by providing real-time feedback and precise movement tracking (Düking et al., 2018). Considering its diverse applications and global potential, sensor fusion-based VR emerges as a versatile tool for enhancing physical training and overall well-being (Chirico et al., 2016). Given its potential impact, a systematic review of the advancements in sensor fusion-based VR for physical training becomes imperative.

This systematic review is intended to probe into the recent advancements in sensor fusion-based VR as a tool for enhancing physical training. In Section 2, we outline our search strategy, inclusion and exclusion criteria, and quality assessment process according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. Section 3 provides an overview of sensor fusion-based VR technology, encompassing the types of sensors commonly used in VR, such as tactile sensors, eye-tracking sensors and inertial measurement units (IMUs). In Section 4, we analyze the current literature on the application of sensor fusion-based VR for improved physical training, including strength training, endurance training, flexibility training, skill acquisition and rehabilitation training, and psychological training. Section 5 delves into the advantages and limitations of using sensor fusion-based VR for physical training, as well as the future research and application direction in this field. Finally, we summarize our findings and emphasize the implications of our review for future research and practice in the field of physical training.

2. Materials and methods

2.1 Search strategy

We conducted an exhaustive literature search in electronic databases including PubMed, Web of Science, Scopus, Embase and IEEE Xplore, using a mix of keywords and MeSH terms concerned with "virtual reality" or "VR" and "physical training" or "exercise" or "fitness" or "skill" or "rehabilitat*" or "mental" or "psycholog*." The search was restricted to articles published between 2018 and 2023. The selected journals and conference proceedings as well as their corresponding publishers are presented in Table 1. A research librarian assisted in developing the search strategy to ensure the identification of all relevant articles. In addition, we manually examined the reference lists of pertinent articles to discover supplementary studies. Duplicate articles were excluded using EndNote software. The study selection process, in accordance with the PRISMA guidelines, is depicted in Figure 1.

2.2 Study selection

In the selection process, two independent reviewers sifted through the titles and abstracts of all retrieved articles to identify potentially pertinent studies. The full articles were subsequently assessed for eligibility according to predefined inclusion and exclusion criteria. Studies were included if they met the following criteria:

- published in English language;
- original research studies;
- involving the use of sensor fusion-based VR technology for physical training; and
- reporting outcomes related to physical training.

Studies were excluded if they:

- were not related to sensor fusion; and
- had multiple publications on the same program.

Disagreements over study selection were resolved through argument and consensus between the two reviewers. The number of studies included and excluded at each stage of the sifting process is reported in the PRISMA flow diagram.

Table 1 Selected journals and conference proceedings as well as corresponding publishers

Publication	Source
IEEE	*IEEE Journal on Selected Areas in Communications*; *IEEE Access*
Elsevier	*Gait & Posture*; *Microprocessors and Microsystems*; *Education for Chemical Engineers*; *Journal of Hand Therapy*; *Medicine in Novel Technology and Devices*
Springer	*Journal on Image and Video Processing*; *Virtual Reality*
MDPI	*Machines Applied Sciences*; *Energies Biomimetics*; *Sensors*; *Electronics Sports*
Taylor & Francis	*Traffic Injury Prevention*
Frontiers Media SA	*Frontiers in Bioengineering and Biotechnology*; *Frontiers in Psychology*
Wiley-Blackwell	*Developmental Medicine & Child Neurology*
Egyptian Knowledge Bank	*Bulletin of Faculty of Physical Therapy*
Hindawi	*Mobile Information Systems*
Human Kinetics	*Case Studies in Sport and Exercise Psychology*; *Journal of Sport Rehabilitation*
ACM	*ACM Transactions on Computing for Healthcare*
SAGE Publications	*Surgical Innovation*
Dove Medical Press	*Clinical Interventions in Aging*
Oxford University Press	*Journal of Public Health*
Mary Ann Liebert, Inc. Publishers	*Games for Health Journal*
BioMed Central	*BMC Geriatrics*
Chitkara University Publications	*Journal of Electronics and Informatics*
Other	Advances in Visual Computing: 13th International Symposium; IEEE Conference on Virtual Reality and 3D User Interfaces (VR); Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies; IEEE REGION 10 CONFERENCE; International Conference on Virtual-Reality Continuum and Its Applications in Industry; International Conference of Information and Communication Technology; International Conferences on Virtual Reality and Visualization; International Conference on Robotics and Automation; International Instrumentation and Measurement Technology Conference; Procedia CIRP; Medical Technologies Congress; Proceedings of the IEEE VR Workshop on Applied VR for Enhanced Healthcare; IEEE Conference on Virtual Reality and 3D User Interfaces

Source: Created by authors

2.3 Data extraction

Data extraction entailed a systematic process of obtaining relevant information from the included studies. Two independent reviewers separately extracted data using a normative form, and any disagreements were resolved through argument and consensus reached with a third reviewer. The data items below were extracted: study design, sample size, participant characteristics (age, gender, health status), intervention details (type of VR technology used, training regimen, duration, frequency), outcome measures (physical performance, functional ability, quality of life, motivation) and any adverse events. Data were extracted using a combination of manual and electronic methods, including direct data entry into a spreadsheet and use of software for text mining and data extraction.

2.4 Quality assessment

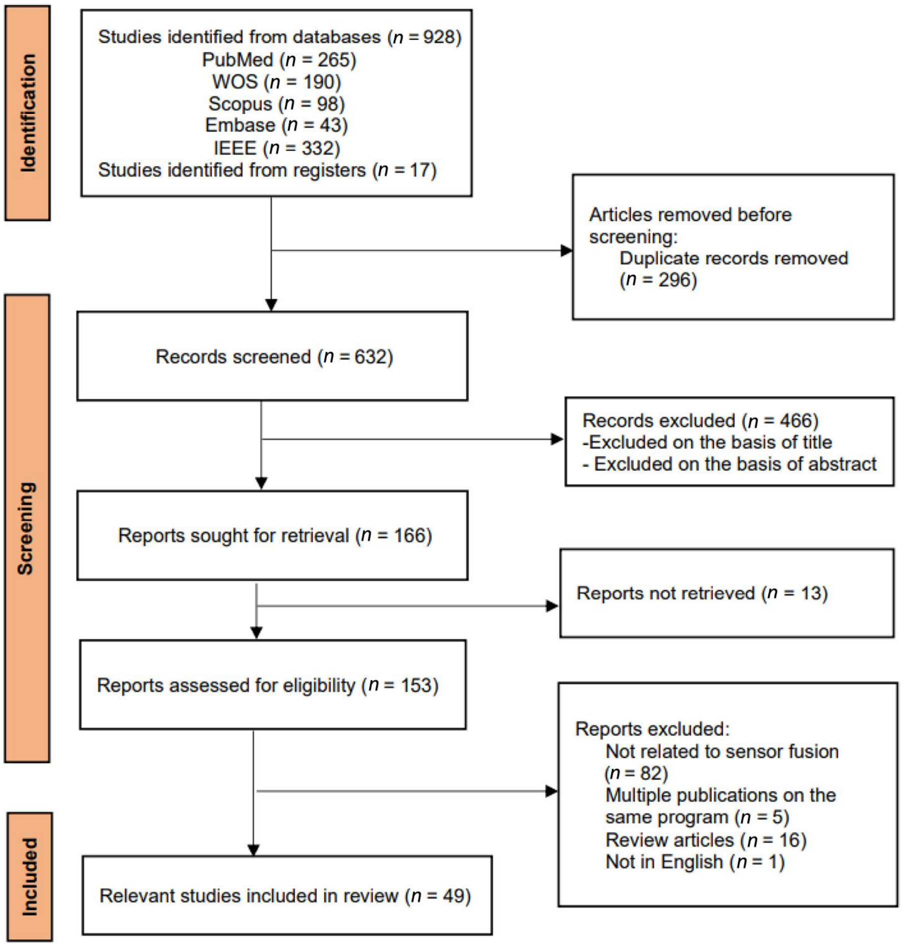
To assess the quality of the included studies, we used the Cochrane risk of bias tool, which estimates the risk of bias across multiple fields, including selection bias, performance bias, detection bias, attrition bias, reporting bias and other sources of bias. The evaluation of bias risk for each study included was undertaken by two independent reviewers. Any disagreements were dealt with through argument or consultation with a third reviewer if required. Furthermore, the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) methodology was used to determine the overall quality of evidence for each outcome. Various criteria, such as bias risk, inconsistency, imprecision, indirectness and publication bias, were considered while assessing the quality of evidence. The quality appraisal was conducted with a systematic and transparent approach to ensure the accuracy and dependability of the results.

3. Sensor fusion in virtual reality

Multisensory fusion, often termed sensor fusion, is integral in creating a more immersive and engaging VR experience (Su *et al.*, 2020). The synthesis of data from various sensors ensures a comprehensive representation of the user's movements and actions within the VR environment, thus leading to a richer interactive experience. In the realm of physical training, sensor fusion's applications in VR are transformative, as they enable an accurate depiction and analysis of an individual's movements and performance.

The VR landscape, particularly in the context of physical training, uses a diverse array of sensors (Qi *et al.*, 2021; Su *et al.*, 2022). These typically include inertial sensors (IMUs), motion capture systems and physiological sensors. First, IMUs measure and report specific force, angular rate and sometimes magnetic field surrounding the sensor. Widely used in physical training VR applications, IMUs can detect the smallest shifts in movements, facilitating granular feedback. By tracking an individual's movement in a 3D space, motion capture systems have profound applications in refining techniques, such as dance or athletic drills. Second, by tracking an individual's

Figure 1 Literature review process



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movement in a 3D space, motion capture systems have profound applications in refining techniques, such as dance or athletic drills. Lastly, physiological sensors capture the body's physiological responses. Heart rate monitors, skin conductance sensors (which measure arousal) and electromyography (EMG) sensors (measuring muscle activity) fall into this category. These sensors are especially crucial in crafting realistic simulations and gauging real-time physiological reactions to training scenarios.

Immersive feedback for training: By fusing data from eye-tracking sensors, IMUs and tactile sensors, VR systems can adapt in real time to the user's actions. For instance, a trainee can receive real-time feedback on their stance or grip in a virtual sport training application, leading to immediate correction and learning (Herrera-Luna *et al.*, 2019).

Realistic simulation of environments: For applications like pilot training or medical simulations, the combination of data from various sensors, such as pressure sensors and heart rate monitors, can create lifelike scenarios (Marin-Pardo *et al.*, 2020). The trainee's physical responses can further influence the virtual environment's response, making the training scenario more dynamic.

Enhanced engagement in rehabilitation: In medical rehabilitation, combining EMG sensors with tactile feedback can offer a more holistic view of a patient's muscle activity (Dhawan *et al.*, 2019). This fusion allows for the creation of customized virtual training regimes, adapting in real-time to a patient's progress.

Precision in skill training: Whether it is a virtual dance class or a martial arts tutorial, the synthesis of data from sensors like IMUs and EMG sensors ensures that the VR system can detect and respond to even the minutest of movements, allowing for refined skill training.

Psychological preparedness training: By integrating feedback from skin conductance sensors, which measure arousal, with the VR environment, training modules can be designed to prepare athletes or soldiers for high-pressure situations, making them mentally resilient.

Beyond the use of sensors, the true essence of sensor fusion lies in the techniques used to process and combine the data they provide. Some pivotal techniques include Kalman filtering, sensor data fusion algorithms and sensor calibration (Qi *et al.*, 2023; Qi and Su, 2022). Kalman filtering refers to a recursive algorithm that estimates the state of a linear dynamic system

Table 2 Experiments with virtual reality (VR) in exercise and fitness training

Author and date of publication	Subjects	Design	Method	Conclusion
Galarza *et al.* (2018)	Three boys and two girls between 8 and 13 years old	An electromyographic sensor-based virtual system using the Unity3D graphics engine	Two videogames with different difficulty levels and easy execution	The acceptation level of the virtual system designed to strengthen the lower limbs of children can be measured
Lin *et al.* (2021)	Eight subjects in active state	A robot-assisted active training (RAAT) using an adaptive admittance control scheme with virtual reality interaction (AACVRI)	Stimulate a virtual training environment including action following, event feedback and competition mechanism	RAAT is a feasible approach for lower limb strength training, and users can independently complete high-quality active strength training under RAAT
De Vries *et al.* (2018)	Thirty young and elderly participants	Seven optoelectronical cameras based on Kinski	Two skiing games, one on the Wii Balance board (Wiiski) and the other with the Kinect sensor (Kinski)	Assessing the movement challenge in games used for balance training is important
Abdelraouf *et al.* (2020)	Fifty male collegiate athletes (football players) from 18 to 24 years old with nonspecific LBP	Oculus Rift DK2 VR headset with embedded sensors	Compare the effect of combined core stability exercises (CSE) and virtual reality (VR) training versus CSE training solely on body balance and function	CSE training plus virtual reality is more effective than CSE training alone in improving total body balance and dysfunction level in collegiate male athletes with nonspecific LBP
Lee and Kim (2018)	Twenty-one male university students	The sports VR system consisting of the IR sensor and the reflector	A program spanning over four weeks which emphasizes enhancing fundamental functions like endurance, strength and function	A four-week virtual reality (VR) training program for sports is suitable for enhancing body composition and overall health through VR-based sports training
Postolache *et al.* (2020)	Two healthy volunteers (one male and one female)	Physical rehabilitation monitoring combining virtual reality serious games and wearable sensor network	Five sessions of 3-min play (180 s) at Cans Down challenge, using both limbs to grab the virtual objects	The remote monitoring of physical training sessions helps the patients to achieve better rehabilitation results in short period of time process
Kern *et al.* (2019)	Thirty-six healthy participants	An immersive VR rehabilitation system that includes a head-mounted display and motion sensors	Compare the immersive program to a traditional rehabilitation program	Immersive VR provides a promising augmentation for gait rehabilitation
Rabbi *et al.* (2018)	Fifteen participants	JARVIS, a virtual exercise aide that offers a fully immersive and interactive gym exercise experience to users	Surface electromyography (sEMG) signal analysis of participants	JARVIS has the potential to deliver effective and engaging guidance for exercises involving machines

Source: Created by authors

from a series of noisy measurements. It is widely recognized for its efficacy in real-time applications. Then, sensor data fusion algorithms are designed to manage, process and combine data from multiple sensors, enhancing the precision and reliability of the results. A crucial step before data fusion, calibration ensures that sensor data is accurate and aligned. Proper calibration can significantly reduce errors in the fused data.

4. Enhanced physical training through sensor fusion-based virtual reality

This section focuses on the application of sensor fusion-based VR technology for enhancing physical training. Table 2 presents representative experiments that have used VR in exercise and fitness training. Moreover, this section provides an overview of the various types of physical training that can benefit from sensor fusion-based VR, including exercise and fitness training, skill acquisition and technique training, injury prevention and rehabilitation training, as well as mental training and preparation. Concurrently, we review the current literature on the employment of sensor fusion-based VR for these types of training, emphasizing the advantages and limitations of this technology.

4.1 Exercise and fitness training

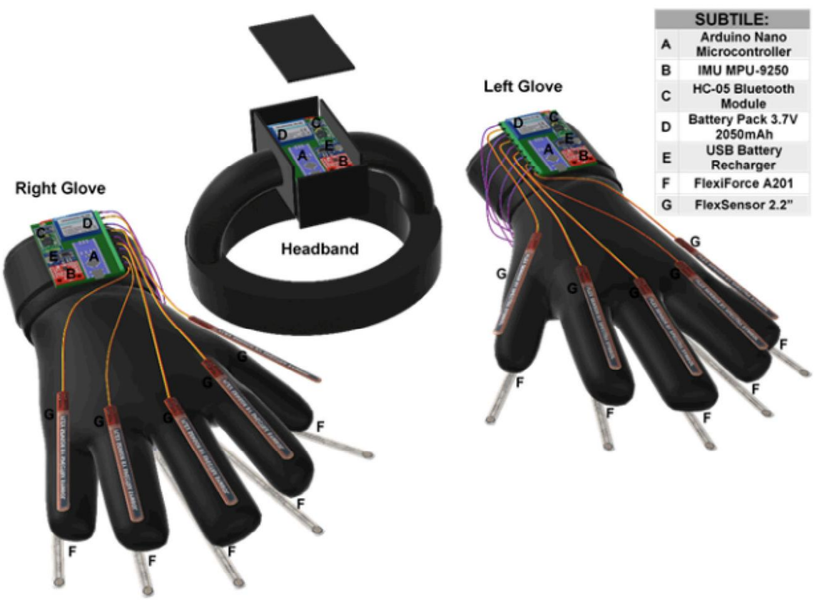
In this subsection, we concentrate on how sensor fusion-based VR can be used to enhance different types of exercise and fitness training, such as strength training, balance training, endurance training and flexibility training. Moreover, we also examine how sensor fusion technology can be used to track and analyze physical performance data, such as heart rate, body temperature and muscle activation. This allows for a more user-friendly human–computer interaction and provides valuable insights for optimizing training experiences.

Virtual systems using sensor fusion-based VR technology have been proposed to enhance lower limb strength training. A virtual system was proposed to fortify children's lower limbs using EMG sensors and Unity3D graphics (Galarza *et al.*, 2018). The system uses Bluetooth wireless communication to collect and process EMG signals, allowing users to control virtual environments. Five users between 8 and 13 years old with muscle affectations participated in experimental tests, and the system's usability was assessed by the single ease question test, yielding a result above 40, which indicates a high level of acceptability. Lin *et al.* (2021) introduced a robot-assisted active training (RAAT) using an adaptive admittance control scheme with virtual reality interaction to improve the lower extremity ability of stroke survivors. Furthermore, terminal force sensors and angular transducers were used to perceive the human–computer interaction force and joint status, while force sensors measured the interaction force and deviations of the dynamic model. Experiments involving eight subjects demonstrated that RAAT is a feasible approach for lower limb strength training.

Sensor fusion-based VR technology has proven to be effective in enhancing balance training, as demonstrated in several studies. de Vries *et al.* (2018) compared the challenge level of two skiing games, Wiiski and Kinski, for balance training in young and elderly participants. The results indicated that Kinski, using seven optoelectronic cameras, imposed a higher challenge level than Wiiski, and adaptations led to a decrease in challenge in Wiiski. This study highlights the importance of assessing movement challenges in games used for balance training, which may have implications for the design and selection of effective balance-training tools. Similarly, a study was conducted to investigate the effectiveness of VR training in improving body balance and function in male collegiate athletes with nonspecific low back pain (Abdelraouf *et al.*, 2020). The Oculus Rift DK2 VR headset, equipped with embedded sensors, was able to detect the wearer's head motions and adjust the displayed images accordingly, producing a stereoscopic 3D image. The experimental group underwent core stabilization exercises while wearing the Oculus Rift DK2 VR headset, resulting in significantly higher postvalues for dynamic balance.

Recently, sports virtual training has demonstrated significant potential in improving endurance and flexibility through the integration of applied sports science, information and communication technology and sensor fusion techniques (Qiao *et al.*, 2021, 2022). A four-week sports VR training program involving 21 participants effectively improved body composition and health, emphasizing the efficiency of VR systems in enhancing endurance and flexibility training (Lee and Kim, 2018). The use of VR serious games and wearable sensor networks enables personalized exercise and improved patient engagement in physical rehabilitation, leading to better results in a shorter period of time (Postolache *et al.*, 2020). An example of wearable sensor devices is shown in Figure 2. Sensor fusion, such as the combination of HMDs and motion sensors, was used in an immersive VR rehabilitation system for treadmill-based programs, resulting in enhanced feelings of competence and superior outcomes compared to traditional

Figure 2 The final prototypes of wearable devices developed, presented on a 3D object schematic with all smart sensors connected in right places



Notes: The green board represents the printed circuit board where are placed all hardware components. The black cover on the headband represents the box of devices and are opened in figure
Source: Figure courtesy of Postolache *et al.* (2020)

training (Kern et al., 2019). JARVIS, a virtual exercise assistant using Internet of Things (IoT) and immersive VR technology, offers an interactive and immersive gym exercise experience by using miniature IoT sensing devices to track exercise information and guide users in proper exercise execution in a virtual environment (Rabbi et al., 2018). The integration of various sensor fusion techniques, including wearable sensor networks, motion sensors and IoT sensing devices, contributes to the effectiveness of VR systems in endurance and flexibility training, ultimately leading to better physical conditions, increased enjoyment and improved competence.

In summary, the current research trends in sensor fusion-based VR for exercise and fitness training highlight the application in enhancing various forms of exercise, from strength to balance to endurance and flexibility. With real-time data analysis, personalized feedback and immersive experiences, there is a clear shift toward more tailored and interactive training regimes. Looking ahead, as sensor technologies become more integrated and sophisticated, and as VR platforms become more widespread, the potential for fully immersive, individualized training sessions in both professional and home settings will only continue to grow.

4.2 Skill acquisition and technique training

This type of physical training focuses on developing specific skills and techniques required for a particular sport or activity as shown in Table 3. VR offers a secure and controlled environment, allowing athletes to practice and hone their abilities, such as shooting accuracy in basketball or ball control in soccer. In addition, sensor fusion-based VR technology can be used to enhance various forms of skill acquisition, including surgical training.

To begin with, VR technologies have been proposed as effective tools for enhancing basketball training. Yao et al. (2020) developed an innovative human action recognition system for VR applications that uses triple Kinect sensors, as illustrated in Figure 3. Unlike previous studies, this system can perform real-time mark detection to identify the user's front and fuse skeleton data. The feasibility of the proposed system has been verified through an experiment using a VR basketball application. In addition, a framework using augmented reality (AR) technology was proposed for basketball training, with the goal of improving the mastery of technical fundamentals and training efficiency (Bao and Yao, 2021). When pitted against each other, the two approaches underscore the dynamism and potential variety in VR applications for basketball training.

Moreover, VR technology shows potential for enhancing athletic training in soccer, as evidenced by the following studies. In Wood et al. (2021), to ensure precise tracking of movements, participants were provided with custom-made training shoes and shin guards tailored to their shoe size. These were specially designed to include four detachable HTC Tracker 2.0 sensors integrated with each shoe and shin guard, enabling precise measurement of movement during soccer-specific VR training. The results of the study confirm the VR simulator's construct validity, as it was able to distinguish between participants of different skill levels, thus demonstrating the potential of VR technology to augment athletic training. Shimi et al. (2021) investigated the influence of attentional abilities on goalkeeping performance in soccer using immersive VR. The findings indicated that attention networks, including alerting, orienting and executive control, significantly contributed to performance in the VR goalkeeping task. This study emphasizes the importance of cognitive skills in sports and highlights the potential for training cognitive abilities in athletes.

Besides, VR can enhance trainees' performance in archery and boxing. Zhang and Tsai (2021) presented a sports training framework based on VR and a motion capture data algorithm. The training experiment results demonstrated that the VR training method could stimulate students' interest in training, improve their training effect and promote their psychological internal motivation to continue training. To assess head–trunk motor coordination and visuomotor transmutation, Esposito et al. (2021) introduced the virtual aRCheRy platform, a VR archery game. The platform was equipped with a pipeline using its own sensor fusion algorithms to analyze both spatial performance and motor behavior. The demonstrative experiment revealed that the egocentric reference frame transition away from the trunk occurred between 7 and 9 years of age. Romeas et al. (2022) found that the 360° VR program led to greater improvements in decision-making performance for boxers. The study highlighted the potential of VR for psycho-perceptual-motor-skill evaluation and training in sports and provided guidance for practitioners.

Researchers have developed various multisensor-based VR systems, such as skiing, shooting and cycling simulators, to improve sports training by overcoming traditional limitations. To address environmental and instructional constraints in conventional alpine ski training, Wu et al. (2019) proposed a VR ski training system using various sensors. The system used motion tracking technology to capture professional skiers' movements and replayed them to users for skill improvement. This laid the foundation for future development and utilization of VR ski simulators to support skiers in their training. Comparatively, Sun and Yang (2022) sculpted a multisensor skiing simulator with safety, training and virtual simulation at its core. On another note, Elor et al. (2020) pitted two immersive VR systems, the Cave Automated Virtual Environment and HMD, against each other, deducing the latter's superior engagement and efficacy. Such comparative insights provide a nuanced perspective on the capabilities and potential areas of improvement for each system. To address the issue of cycling enthusiasts being unable to ride outside due to weather and traffic accidents, a VR cycling system with multisensor fusion is proposed (Liao et al., 2020). Hall sensors, gyroscopes and other sensors are used to capture cycling speed and rotation angle, while real-time data exchange with a mobile VR scene enables monitoring of movement consumption, speed and distance. In addition, the system simulates natural wind effects using a fan, resulting in a more realistic indoor VR cycling experience.

Diving into professional skills like welding, Lee et al. (2021) launched a sensor-rich extended reality platform tailored for arc welding, offering an immersive welding ambiance. Contrasting this with surgical training, Queisner et al. (2022) capitalized on depth sensors and cameras to forge the VolumetricOR system, facilitating dynamic 3D visualizations in operating theaters. While both domains are drastically different, juxtaposing the VR applications underscores the versatility and potential customization based on the specific training needs.

Table 3 Experiments with virtual reality (VR) in skill acquisition and technique training

Author and date of publication	Subjects	Design	Method	Conclusion
Yao *et al.* (2020)	Five three-dimensional (3D) skeleton data sequences from body parts	A novel system for recognizing human actions in VR applications using three Kinect sensors	A method for detecting marks in real-time to identify the user's front and fuse skeleton data	The system's feasibility has been demonstrated through the use of a virtual reality basketball application
Bao and Yao (2021)	Basketball players	The framework for reproducing basketball training using augmented reality technology	Basketball technology's mode founded on virtual reality-based virtual data augmentation technology (VDRT)	Players can gain crucial insights into sports skills, leading to a substantial enhancement in basketball players' training efficiency
Wood *et al.* (2021)	Seventeen professional soccer players (13 male, 4 female), seventeen academy players (14 male, 3 female) and seventeen novice players (9 male, 8 female)	A soccer-specific VR simulator	Four VR soccer drills per group	VR platform effectively distinguished between participants of varying skill levels
Shimi *et al.* (2021)	One hundred volunteers (34 males and 66 females)	VR goalkeeper task	Three computerized tasks and the two paper-and-pencil scales	Cognitive skills relating to attention play a critical role in the efficient execution of soccer-specific tasks
Zhang and Tsai (2021)	High-school students learning tennis for the first time	The framework of sports training based on virtual reality technology and a motion capture data algorithm based on behavior string	The training method using virtual reality technology	VR training method can stimulate students' interest in training, improve students' training effect and promote students' psychological internal motivation to continue training
Esposito *et al.* (2021)	Adults, 10-to 11-year-old children and 6- to 7-year-old children	The VRCR platform	A virtual reality archery-like serious game for the assessment of head–trunk motor coordination, head–trunk visuomotor transformation, egocentric space encoding and their relationship	The VRCR platform is useful in simplifying the study of such a complex system by disentangling its components
Romeas *et al.* (2022)	Six boxers	A 360° VR (360VR) temporal video-occlusion program	One experimental group trained on 360VR, and one active control group trained on a VR game simulation during 11 sessions	360VR offered self-reported satisfactory, representative and safe individual training opportunities for the boxers
Wu *et al.* (2019)	Fourteen participants (6 female)	A ski training system using virtual reality technology and an indoor ski simulator	One training trial to get familiar with the visualization and two test trials	The VR-based ski simulator offered users an immersive skiing experience and enabled them to overcome environmental limitations associated with alpine ski training through the use of relatively inexpensive equipment
Sun and Yang (2022)	Skiing participants	The attitude training simulator of ski machine with multisensor	A stimulated training that helps people simulate multidimensional skiing posture in real skiing scene experience	The attitude training simulator based on multisensor technology can demonstrate favorable benefits in practical applications
Elor *et al.* (2020)	Forty participants with and without cognitive disabilities	The Cave Automated Virtual Environment (CAVE) and the head-mounted display (HMD)	Compare the room-scale Mechdyne CAVE and HTC Vive Pro HMD with a custom in-house exercise game	The HMD exhibited exceptional performance within the game, eliciting a positive biofeedback response and promoting player engagement
Liao *et al.* (2020)	Cycling enthusiasts	A virtual reality cycling system with multi-sensor fusion	The virtual simulation scene of bicycle riding built through the virtual reality environment of mobile phone	The indoor VR cycling effect can be realized

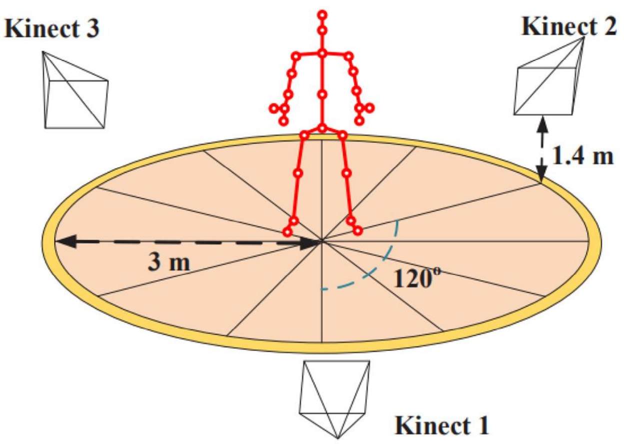
(*continued*)

Table 3

Author and date of publication	Subjects	Design	Method	Conclusion
Lee *et al.* (2021)	Platform users	A new multisensor extended reality platform for arc welding training	A "bot trainer," virtual cues of the seam geometry, automatic spot tracking and performance scores	The automated multisensor technique demonstrated superior performance in terms of precision, learning curve and efficacy
Queisner *et al.* (2022)	Trainees	A photorealistic virtual operating room	Traditional video-based formats of digital simulation in surgical training	VolumetricOR improved the linking of theoretical expertise and practical application of knowledge and shifts the learning experience from observation to participation

Source: Created by authors

Figure 3 Schematic illustration of the Three Kinect System



Source: Figure courtesy of Yao *et al.* (2020)

Summarizing, the current research trends in the domain of skill acquisition and technique training using sensor fusion-based VR emphasize the technology's capability to create realistic training scenarios for diverse sports and professional activities. These technologies provide a bridge between the virtual and real worlds, allowing for safe, controlled and effective training. From sports like basketball and skiing to professional skills like welding and surgery, VR is proving to be an indispensable tool. As we move forward, the fusion of more sensors and the development of more realistic virtual environments are expected, ensuring that athletes and professionals can train more effectively and safely than ever before.

4.3 Injury prevention and rehabilitation training

This form of physical training, as depicted in Table 4, concentrates on minimizing the risk of injuries and expediting the recovery process following an injury. VR can be used to replicate real-life scenarios and movements that potentially expose a subject to injury, thereby enabling them to practice and refine appropriate techniques and movements to avert injury.

VR interventions have been explored in recent studies for their potential to enhance pedestrian safety and occupational safety. In one study, Phu *et al.* (2019) evaluated the effectiveness of VR training with the Balance Rehabilitation Unit compared to the modified Otago Exercise Programme in enhancing physical performance and balance among older adults with a history of or at risk of falls. The results demonstrated that both interventions significantly improved timed up and go, gait speed, limits of stability in posturography assessment, falls efficacy scale – international score and handgrip strength compared to the nonintervention group. Luo *et al.* (2020) examined the application of VR technology for pedestrian safety training in Chinese children, aiming to identify and modify risky pedestrian behaviors through three street-crossing challenges. The study used two infrared sensors to construct a large tracking space. In 2022, through a virtual environment that simulates tractor operation and rollover hazards, VR intervention Virtual Reality Intervention for Safety Education (VRISE) enhances the perceived threat of tractor-related accidents and improves tractor safety intentions (Namkoong *et al.*, 2022). The research underscores the effectiveness of VR interventions like VRISE in promoting behavioral intentions for occupational safety.

Recent research has explored the potential of VR to address challenges and enhance training in various industries, including the chemical, precast concrete and smart grid industries. Fracaro *et al.* (2021) discussed the potential of VR as a solution to obstacles in chemical industry operator training, such as high costs, safety limitations and lack of engagement. Their work contributes to a multidisciplinary exploration of VR training environments within the chemical industry. In Joshi *et al.* (2021), a safety training module was created using Unity3D and Visual Studio platforms, interfaced with Oculus Rift/Oculus S and equipped with Oculus sensors to reduce the occurrence of common injuries in the precast/prestressed concrete industry. The module focused on three significant safety concerns. He *et al.* (2022) introduced a vectorized graph convolutional deep learning model aimed at assessing the precision of manual operations within VR training systems designed for smart grids. The model uses multisensor data sets obtained from data gloves and is capable of reducing data

Table 4 Experiments with virtual reality (VR) in injury prevention and rehabilitation

Author and date of publication	Subjects	Design	Method	Conclusion
Phu *et al.* (2019)	195 participants with a risk and/or history of falls	Balance Rehabilitation Unit (BRU) and a modified Otago Exercise Programme (EX)	The study compared participants receiving interventions to a control group, assessing their physical performance	Virtual reality can improve outcomes of balance training
Luo *et al.* (2020)	79 children from three elementary schools	A VR program comprising three street-crossing challenges	Participants completed pedestrian challenges twice, with debriefing in between, and their risky behaviors were analyzed	VR is effective for correcting risky pedestrian behaviors in Chinese children
Namkoong *et al.* (2022)	291 high school students	Virtual Reality Intervention for Safety Education (VRISE)	VRISE was developed, and subjects were randomly assigned to the treatment or two control groups	VRISE can effectively improve public health outcomes in occupational safety education
Fracaro *et al.* (2021)	Industrial participants	A VR training solution	The VR training environment comprised game-based learning components, evaluation methods and learning analytics	VR training environments can assist the chemical industry
Joshi *et al.* (2021)	32 students from Mississippi State University	A VR training module	VR training module is evaluated through efficacy and effectiveness analyses	VR training is characterized by higher engagement and yields a deeper comprehension of concrete plants
He *et al.* (2022)	Trainees	A vectorized graph convolutional deep learning model	The model constructs a kernel with different weights for finger joints and uses different evaluation strategies for different actions	The method for evaluating manual operation accuracy in VR training systems of smart grids is efficient
Kumar *et al.* (2018)	12 hemiplegic patients	Virtual reality-based CoM-assisted balance tasks (Virtual CoMBaT)	Participants interact with Virtual CoMBaT through ankle strategy for weight shifting and complete tasks of varying challenge levels	The system can improve overall performance in balance-related tasks of varying difficulty levels
de Vries *et al.* (2020)	Thirty young and thirty healthy older adults	VR balance games	EMG was used to monitor muscle activity in young and healthy older adults as they played seven VR balance games	The method analyzed muscle activity during VR games and identified potential strength training elements
Zahedian-Nasab *et al.* (2021)	60 elderly individuals living in nursing homes	VR exercises based on Xbox Kinect	The study used demographic questionnaires, the Berg Balance Scale, the Timed Up and Go test and the Falling Efficacy Scale as research tools	VR balance exercises for 6 weeks improved balance ability and reduced fear of tumbling in the elderly
Bai and Song (2019)	32 participants	A home-based multiscene upper limb rehabilitation training and evaluation system	An FMA-RSA model assessed upper limb motor function, and dynamic time warping solved movement path inconsistencies	The system has the potential to become an effective home rehabilitation training and evaluation system
Liu *et al.* (2019)	Users	A glove-based system	A network of 15 IMUs is deployed, and hand location is tracked by a Vive Tracker with a Lighthouse	Such a glove-based system can simplify the data collection of human manipulations with VR
Tarakci *et al.* (2020)	92 patients	An 8-week LMCBT program	A randomized control trial comparing LMCBT to conventional treatment was conducted on children and adolescents with different disabilities	The use of LMCBT should be considered as an effective intervention for children and adolescents experiencing physical disabilities
Li *et al.* (2023)	Patients with severe hand impairment	Inexpensive soft robotic glove for hand rehabilitation in VR	A glove with 15 inertial measurement units and a motor–tendon stimulus system tracks finger motion	The proposed glove could be used as a simple method for assessing and training hands
Marin-Pardo *et al.* (2020)	Four stroke survivors	An EMG-based variant of our REINVENT VR neurofeedback rehabilitation system	Participants underwent seven 1-h training sessions using a head-mounted VR system and clinical assessments were conducted	Training with MCIs improved clinical assessment scores and induced changes in corticospinal communication
Xiao *et al.* (2022)	Patients with movement disorders	A virtual reality rehabilitation system based on Kinect	Patients control their virtual role using Kinect, following guidance for training actions	The virtual reality upper limb rehabilitation system is proven reliable, stable and effective in guiding users

(*continued*)

Table 4

Author and date of publication	Subjects	Design	Method	Conclusion
Alexandre *et al.* (2019)	Patients	A solution for physical rehabilitation of upper limbs based on VR	A Web API processed sensor data, providing insights on user capabilities during training	The developed system proves to be an appropriate solution that can be used in the physiotherapy area
Choi *et al.* (2021)	80 children with brain injury	A virtual reality rehabilitation system of wearable multi-inertial sensors	Eighty children beset by brain injury participated in a randomized controlled trial and assessments were conducted using evaluation tools	In comparison to conventional occupational therapy, virtual reality training proved to be more effective in enhancing dexterity
Shi and Peng (2018)	Patients	A VR-based user interface	QFD and ergonomic analysis used to enhance the interest of patients and improve their rehabilitation	Game playing using the developed interface improves patient rehabilitation
Covaciu *et al.* (2021)	People who have had a stroke	A VR simulator for an intelligent robotic system	This simulator uses sensors including gyroscope, accelerometer and EMG to collect data on foot movement and muscle activity	By using this intelligent module by the rehabilitation system, the patient's recovery process can be improved
Akbulut *et al.* (2019)	Unimpaired healthy participants	A low-cost, effective rehabilitation system	Researchers used the Kinect sensor, sEMG sensor and Oculus Rift headset to extend therapeutic interaction	The proposed system functions effectively in a domestic setting

Note: FMA-RSA = Fugl-Meyer assessment and relative surface area
Source: Created by authors

dimensionality. The proposed approach for evaluating the accuracy of manual operations has demonstrated effectiveness in VR training systems for smart grids.

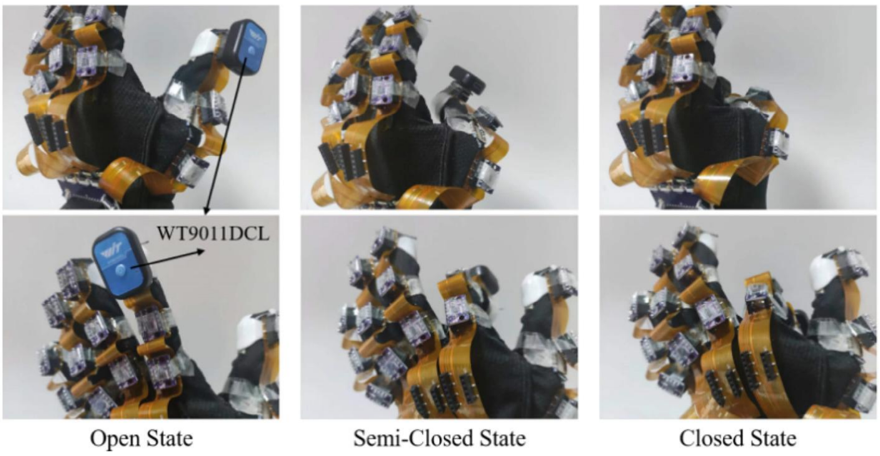
According to recent studies, the potential benefits of using VR in various areas such as poststroke rehabilitation, balance training and fall prevention among the elderly have been analyzed. A platform incorporating technology-based solutions, such as VR and readily available sensors like the Nintendo Wii balance board and Kinect, was created to design captivating balance exercises for individuals with poststroke hemiplegia (Kumar *et al.*, 2018). The platform, named Virtual CoMBaT, was developed to adjust to an individual's weight-shifting capacity and provided tasks of varying difficulty levels while following the ankle strategy for weight transfer. de Vries *et al.* (2020) investigated the intensity and duration of muscle activity in VR balance games using surface EMG and Kinect cameras. The study found that the muscle activity during gameplay was predominantly low and prolonged activation was lacking; however, it identified game elements that could potentially provide a strength training stimulus. In a study by Zahedian-Nasab *et al.* (2021), the influence of VR exercises based on Xbox Kinect, which executes and recognizes movements through infrared motion sensors and a camera, was examined in relation to balance and fear of falling among older adults. The intervention group received VR exercises, while the control group participated in routine nursing home exercises. Results demonstrated that VR exercises significantly improved balance ability and mitigated fear of tumbling in elderly participants.

VR technology has been applied to improve the control of upper limb movements, stable grasping, and hand and finger movements. Bai and Song (2019) presented a novel, low-cost home-based upper limb rehabilitation and evaluation system for poststroke patients using the Kinect sensor and posture sensor. The system featured multiple virtual scenes for upper limb and trunk rehabilitation, as well as a rehabilitation evaluation method that integrated the Fugl-Meyer assessment and reachable workspace relative surface area. Results indicated that the system effectively improved upper limb motor control function, with the highest forecast accuracy of 92.7%, demonstrating its potential as a home rehabilitation training and evaluation system. A glove-based system that combined hand pose sensing, hand localization and haptic feedback for stable grasps in VR was proposed (Liu *et al.*, 2019). The glove-based system used a network of 15 IMUs for real-time hand pose sensing and a Vive Tracker for hand localization. The proposed glove-based design demonstrated a higher success rate, simplifying data acquisition of human operations within VR environments. Tarakci *et al.* (2020) proposed a Leap Motion Controller–based training (LMCBT) to evaluate its efficacy in children and adolescents beset by physical disabilities. The study innovatively used a Leap Motion Controller to track hand and finger movements in video game-based training with motion sensor interactions, as well as VR. The findings indicated that LMCBT could serve as a viable alternative treatment for children and adolescents suffering from physical disabilities.

In addition to motion control, VR technology has also been used for sensory training. Li *et al.* (2023) introduced an affordable soft robotic glove for hand rehabilitation in VR, providing force feedback to the fingers, enabling users to feel the force of a virtual object. The glove contained fifteen IMUs to track finger motion and simultaneously calculate the gestures of all five fingers using static threshold correction and complementary filter algorithms. Figure 4 depicts different states of the glove during static tests. The proposed data glove demonstrated precise and stable finger motion tracking, as evidenced by the results of both static and dynamic tests.

Moreover, VR technology could combine the aforementioned aspects to enhance neuromuscular functions. In a pilot study by Marin-Pardo *et al.* (2020), the feasibility and effectiveness of

Figure 4 Open state, semi-closed state and closed states for static tests



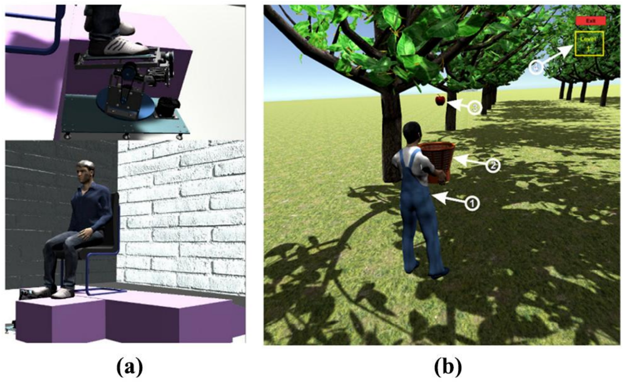
Source: Figure courtesy of Li *et al.* (2023)

EMG-based variant of the REINVENT VR neurofeedback rehabilitation system were explored. The system aimed to promote volitional muscle activity and reduce unintended co-contractions in patients with severely restricted active wrist movement in the chronic stage of stroke recovery. The study recruited four participants who completed seven 1-h training sessions using the VR system, suggesting potential for functional recovery and neural plasticity. The study highlighted the potential of using muscle–computer interfaces as a simpler and equally effective alternative to brain–computer interfaces in stroke rehabilitation. Xiao *et al.* (2022) proposed a VR rehabilitation system based on the Kinect sensor for stroke patients in Brunnstrom Stage III or above. The system provided a personalized training plan, real-time motion data collection and adaptive guidance to help patients correct compensatory patterns. Two experiments demonstrated the accuracy of range of motion and the effectiveness of virtual guidance, showcasing the potential of the system to improve rehabilitation outcomes.

The following two paragraphs discuss the development and evaluation of VR rehabilitation systems aimed at improving upper-limb and lower-limb functions.

VR-based solutions incorporating IoT wearable devices and smart sensors have been designed to rehabilitate the upper limb. In Alexandre *et al.* (2019), a VR-based solution for upper limb rehabilitation that used IoT wearable devices and smart sensors was proposed. The system comprised a headband and two gloves equipped with smart sensors, which communicated with the VR platform via Bluetooth. Experimental data on upper limb and finger motion during rehabilitation sessions yielded satisfactory results (Chen and Qiao, 2020b; Chen *et al.*, 2022). Choi *et al.* (2021) evaluated the effectiveness of a VR rehabilitation system using wearable sensors to improve upper-limb function in children suffering from brain injuries. The outcomes indicated that, when used in conjunction with conventional occupational therapy, the VR group exhibited more significant advancements in upper-limb dexterity, performance of daily activities and forearm supination. To create a user-friendly interface for upper limb

Figure 5 (a) Virtual patient who performs rehabilitation exercises with robotic structure and (b) virtual human character picking apples



Source: Figure courtesy of Covaciu *et al.* (2021)

rehabilitation, Shi and Peng (2018) proposed a solution that used VR technology. They used a VR-based interface with Unity3D software and a Kinect motion sensor to identify patients' needs. By incorporating game elements, the interface enhanced patients' engagement and rehabilitation outcomes.

In addition to its application in upper-limb rehabilitation, VR technology has also been used for the rehabilitation of lower limbs. Covaciu *et al.* (2021) introduced the development of a VR simulator for ankle rehabilitation after a stroke. The simulator used sensors equipped with a gyroscope and accelerometer to detect and track the patient's motions and muscle activity. Furthermore, it featured an intelligent module that used machine learning to create personalized exercises within a virtual environment, as depicted in Figure 5. Consequently, the simulator reduced dependence on therapists and enhanced patient motivation. Akbulut *et al.* (2019) discussed the development of four diverse serious games designed for rehabilitating phantom limb pain syndrome. The proposed low-cost, effective rehabilitation system incorporated the use of Kinects, EMG sensor and Oculus Rift VR headset, facilitating extended therapeutic interaction between the patient and the cybertherapy environment. Alpha testing with unimpaired healthy participants yielded promising results for practical use in a home setting.

The application of VR in physical training showcases a paradigm shift from traditional methods to technology-driven approaches. The latest trend encapsulates a comprehensive application of VR in motion control, sensory training and neuromuscular retraining. As the field advances, we may anticipate more intuitive and immersive VR environments, possibly integrated with biofeedback mechanisms, that can adapt in real time to the user's physiological and psychological states. Future studies might also delve deeper into understanding the long-term impacts of VR-based physical training and its holistic benefits.

4.4 Mental training and preparation

VR technology has been increasingly applied in various domains, including psychological training, neurological disease treatment, posttraumatic stress disorder (PTSD) therapy and emergency fire training. As described in Table 5, researchers have used an array of sensors and intelligent devices for data collection. The findings reveal that VR technology holds significant potential for enhancing balance, alleviating pain, mitigating psychological stress, treating PTSD and augmenting emergency response capabilities.

Numerous studies have investigated the potential of VR technology for therapeutic applications. Flores *et al.* (2018) examined the feasibility and efficacy of using immersive VR to enhance dialectical behavioral therapy (DBT) mindfulness skills training in reducing psychological symptoms in two spinal cord injury patients. Both patients reported experiencing

Table 5 Experiments with virtual reality (VR) in mental training and preparation

Author and date of publication	Subjects	Design	Method	Conclusion
Flores *et al.* (2018)	Two patients with SCI	Immersive virtual reality (VR) enhanced DBT® mindfulness skills training	Each patient looked into VR goggles and had the illusion of slowly "floating down" a river in virtual reality while listening to DBT® Mindfulness Skills training instructions	Both SCI patients accepted VR, the patients liked using VR, and, with assistance from the therapist
Smys *et al.* (2019)	Individuals who have experienced trauma as a result of incidents such as accidents, war, sexual abuse and similar situations	VR technology based on several sensors	Gather the user movements on a motion platform and replicate it in the virtual environment with the help of a Raspberry Pi board and Unreal Developer's kit	VR can effectively boost the PTSD therapy
Rings *et al.* (2019)	Patients with neurological diseases	Exergames in virtual environments (VEs)	Innovative therapy methods using immersive VR technology	VR-based games required motor, mental and cognitive efforts to follow the dual-task-paradigm through complex motor–cognitive tasks
Clifford *et al.* (2019)	Twelve professional firefighters from the Air Attack training cohort (eleven males and one female)	A multiuser, collaborative, and multisensory (vision, audio, tactile) VR system	Two separate experiments to compare the multisensory VR simulator with two conventional training methods: real-world field exercises and radio role-playing in a room	No significant differences between the VR training exercise and the real-world exercise in terms of the level of stress
Šalkevicius *et al.* (2019)	Thirty subjects (seventeen males and thirteen females)	Cloud-based VRET system	A model of public speaking anxiety involving four levels of anxiety recognition	The best performing VRET stimuli-based models had a window length between 20 and 25 s
Nambi *et al.* (2021)	Fifty-four university American soccer players with chronic low back pain	Virtual reality training	Various exercises for enhancing balance over a duration of four weeks	Training through virtual reality is an effective treatment program when compared with conventional exercise training programs from a psychological and hormonal analysis perspective
Harrison *et al.* (2021)	Thirteen female soccer players	Oculus Quest with a virtual relaxation session from the Liminal VR application	Three blocks of five penalty kicks against a goalkeeper	VR played an initial step to evaluate relaxation interventions on performance in female soccer players
Köyağasıoğlu *et al.* (2022)	Fifty-seven healthy adults (twenty-eight females, twenty-nine males)	Virtual reality mental training (VRMT)	VR head-mounted display and non-immersive computer screen training, each lasting for 30 min, conducted three days per week for a period of four weeks	VRMT may be superior to CMT in improving balance test results

Source: Created by authors

decreased depression, anxiety and emotional distress following VR-enhanced DBT mindfulness skills training. Moreover, Patient 2 reported substantial reductions in short-term ASD/PTSD symptoms after the initial VR DBT mindfulness skills training session. Smys *et al.* (2019) explored the use of VR technology to create virtual environments that aid in PTSD therapy for individuals affected by trauma. Through the use of different motion platforms and sensors, movements can be simulated within a virtual setting, enabling clinicians to adapt to the environment according to the patient's requirements. In addressing neurological diseases such as Parkinson's and dementia, an interdisciplinary collaboration, EXGAVINE, was proposed (Rings *et al.*, 2019). The project used IMUs and vibrotactile feedback to inform patients of incorrect movements while concentrating on innovative VR-based games that demand both motor and cognitive efforts.

Meanwhile, the application of VR technology in health care and anxiety ease has been further explored. Clifford *et al.* (2019) investigated the use of a multisensory VR system for aerial firefighting training scenarios, as depicted in Figure 6, and compared it to real-world and radio-only exercises. According to the study's findings, there were no noteworthy variations in stress levels between VR and real-world exercises. In addition, no significant distinction was observed between VR and radio-only exercises based on HRV and SSSQ evaluations. Šalkevicius *et al.* (2019) explored the potential of combining VR exposure therapy (VRET) with mental stress detection to efficiently track a patient's anxiety levels during treatment. Through the use of wearable biofeedback sensors to collect physiological signals, a model of four-level anxiety recognition achieved 80.1% accuracy across subjects and 86.3% accuracy with 10 × 10-fold cross-validation.

Lastly, VR technology has been emphasized in various aspects of sports, health and psychology. Nambi *et al.* (2021) evaluated the short-term effects of sensor fusion-based VR training on chronic low back pain in American soccer players, in comparison with combined physical rehabilitation and control groups (Chen and Qiao, 2020a). The VR training group showed significant improvements in pain intensity, kinesiophobia and hormonal variables compared to the other two groups. Harrison *et al.* (2021) investigated the effectiveness of a VR relaxation intervention on reducing anxiety and improving penalty kick performance in female soccer players. The study collected physical data using Kinematics and Polar H10 sensors to appraise the physical effects of stress and VR on the participants. Results showed significant reductions in cognitive and somatic anxiety and increased self-confidence, supporting the potential of VR relaxation interventions in sport. A randomized controlled trial investigated the effects of mental training programs on balance skills and hemodynamic responses of the prefrontal cortex in healthy adults (Köyağasıoğlu *et al.*, 2022). Conventional and VR mental training significantly enhanced balance test outcomes, with some added benefits observed in the VR group, a motor–tendon actuation system.

Figure 6 A trainer observed the trainee AAS to assess their performance

Note: Previously, this was only conducted in a real helicopter without any fire
Source: Figure courtesy of Clifford *et al.* (2019)

However, while there is ample evidence to suggest the positive implications of VR technology, there remain unresolved issues and gaps in the existing literature. For instance, many studies focus on the immediate outcomes of VR interventions, but long-term implications and potential side effects are less documented. There is also a disparity in the methods and standards used in various studies, making cross-comparative analyses challenging. Moreover, while certain populations have been extensively studied, like sports professionals or specific patient groups, other potential beneficiaries of VR, such as elderly individuals or children with developmental disorders, are underrepresented in the current literature.

In light of the aforementioned studies, current research trends indicate a strong inclination toward harnessing VR technology in diverse areas ranging from medical therapies to sports training. This multifaceted application of VR is underpinned by its capability to create controlled, immersive environments, which when combined with sensor technologies offers precise data-driven insights. As for future prospects, it is anticipated that as VR technology evolves and becomes more accessible, its integration with artificial intelligence (AI) and other emerging technologies will further its potential in medical and therapeutic applications, providing more personalized, immersive and effective interventions for patients and individuals across various domains.

5. Discussion

The implementation of sensor fusion-based VR systems in physical training presents a transformative approach to traditional methods. The multifaceted benefits of this integration span across various domains of physical training, substantiated by empirical research. First, in exercise and fitness training, real-time feedback is paramount. Sensor fusion allows for this immediate monitoring, enabling users to hone in on specific fitness metrics, including strength, balance, endurance and flexibility (Lin *et al.*, 2021; Abdelraouf *et al.*, 2020; Postolache *et al.*, 2020; Rabbi *et al.*, 2018). This personalized approach enhances workout efficiency and effectiveness, leading to superior overall outcomes (Lee and Kim, 2018). Furthermore, the immersive nature of VR environments can improve user motivation and engagement, leading to increased adherence and enjoyment during fitness training (Postolache *et al.*, 2020). Beyond basic fitness, the acquisition of specialized skills demands precision. Sensor fusion-enhanced VR systems cater to this requirement, furnishing meticulous feedback on user movements and postures (Wood *et al.*, 2021). This level of feedback is often challenging to achieve in traditional training settings, making VR systems an invaluable tool for skill acquisition and mastering complex techniques. Another domain where sensor fusion-based VR shines is in injury prevention and rehabilitation. These systems are adept at tailoring training programs, molding them to fit an individual's unique profile – taking into account their needs, constraints and progression (Kumar *et al.*, 2018; de Vries *et al.*, 2020; Xiao *et al.*, 2022). By closely monitoring user movements and providing real-time feedback, these systems can help ensure proper exercise execution, reducing injury risk and facilitating a safer and more efficient rehabilitation process (Namkoong *et al.*, 2022). Lastly, mental preparedness, an often-underestimated aspect of physical training, is crucial. Sensor fusion-based VR platforms recreate high-fidelity, challenging scenarios that facilitate the honing of mental faculties like focus, visualization and stress handling (Rings *et al.*, 2019; Šalkevicius *et al.*, 2019; Harrison *et al.*, 2021). This immersive experience fosters mental resilience and preparedness, essential aspects of overall performance in various physical activities (Clifford *et al.*, 2019).

However, alongside these merits, several challenges arise that may hinder the technology's widespread adoption and efficacy, including sensor accuracy, cost, user acceptance, system design and data privacy. A significant challenge in implementing sensor fusion-based VR systems in physical training is the accuracy and reliability of the sensors. Ongoing research and development should focus on advanced calibration techniques, AI-driven error correction and multisensor redundancy to ensure accurate and reliable data capture (Yang, 2018). Another challenge in the adoption of sensor fusion-based VR systems is the cost and accessibility of the technology (Olshannikova *et al.*, 2015). The financial barrier of high-quality VR and sensor systems may limit their broader accessibility. Collaboration between academia, industry and governmental bodies to subsidize costs, develop cost-effective sensor systems and promote widespread VR literacy can pave the way for more universal accessibility. User acceptance and adaptation to VR-based training is another potential challenge (de Vries *et al.*, 2018). While VR offers immersion, users might face discomfort or disorientation (Kim *et al.*, 2018). Personalized user interfaces, adjustable environment settings and user education sessions can enhance acceptance and decrease discomfort during initial VR exposures. The effectiveness of sensor fusion-based VR systems in physical training may also depend on the quality of the virtual environments and the degree of customization offered (Galarza *et al.*, 2018; Postolache *et al.*, 2020). Creating realistic, dynamic and adaptive virtual environments that cater to individual users' needs can be technically challenging and resource-intensive. Collaborative design approaches involving end users, incorporation of real-world physics and adaptive algorithms that learn from user behavior can lead to more user-centric VR environments. Lastly, privacy and security concerns may arise when dealing with personal data collected by sensor fusion-based VR systems (Adams *et al.*, 2018). Adopting stringent encryption methods, transparent data handling policies and regular third-party security audits can safeguard users' trust and ensure data protection.

Looking forward, by concentrating on the development of advanced sensor technologies and integrating VR with other emerging technologies, VR systems are anticipated to provide more accurate, immersive and personalized experiences. The ongoing development and effectiveness of VR systems in physical training are closely tied to advancements in sensor technologies (Anthes *et al.*, 2016). Researchers and developers should investigate innovative sensor designs, advanced data processing methods and novel materials that can optimize sensor performance, enhancing accuracy, response time and reliability (Zhao and Lv, 2023). Improved sensor technologies will contribute to more efficient sensor fusion-based VR systems, leading to better training outcomes and user experiences. Merging VR with other emerging technologies, such as AR, mixed reality (MR) and haptic feedback, will elevate the training experience by creating more realistic, engaging and interactive virtual environments (Han *et al.*, 2022; Morimoto *et al.*, 2022; Goyal *et al.*, 2022). The incorporation of AR can provide real-time, context-aware information overlays to enrich users' training experiences, while MR can blend the best aspects of both VR and AR, offering a more immersive and versatile environment. Haptic feedback technologies can introduce tactile sensations, enabling users to feel physical responses to their actions, resulting in a more realistic and intuitive experience. These integrations will not only benefit physical training but also find applications in various other fields, such as education, health care and entertainment.

While the research findings delineated in this systematic review unmistakably spotlight the transformative attributes of sensor fusion-based VR systems in physical training, it is essential to acknowledge certain limitations and potential biases inherent in the studies reviewed. Some investigations might be influenced by sampling biases, technological constraints or methodological discrepancies, which could impart a slant to the outcomes. Furthermore, the rapid pace of technological advancement implies that certain studies might operate on assumptions or use technologies that could become obsolete or surpassed in the near future. This fluidity in the tech domain necessitates continuous adaptation and validation of the findings, ensuring they remain relevant and accurate. From an academic perspective, this review enriches the burgeoning body of literature on VR and sensor fusion applications in physical training. It offers a comprehensive examination of the present landscape, pinpoints prevailing research voids and paves the way for future scholarly endeavors. Embracing a holistic stance, it is pivotal to champion interdisciplinary cooperation across domains like sports science, computer science and engineering. Such collaboration is instrumental in conceptualizing avant-garde solutions to grapple with the intricacies and challenges tethered to sensor fusion-integrated VR systems in physical training (Liu *et al.*, 2023; Wang *et al.*, 2022). In the realm of practicality, the insights distilled from this review are poised to shape the blueprint and execution of sensor fusion-based VR systems across an array of physical training verticals. By delineating both the strengths and potential pitfalls of these systems, professionals are empowered with a more nuanced comprehension, aiding them in making judicious decisions about the infusion of VR technologies into their regimes. This balanced understanding augments the prospects of maximizing effectiveness, safety and user immersion in physical training experiences.

6. Conclusion

In this systematic review, we have rigorously examined the contemporary research and applications of sensor fusion-based VR systems in physical training. Our exploration spanned domains like exercise and fitness training, skill refinement, injury prevention, rehabilitation and mental preparedness. The principal takeaways and recommendations from this study underline the transformative potential of such systems in redefining the landscape of physical training. Sensor fusion, when synergized with VR, brings forth manifold benefits for physical training. These advantages manifest in elevated effectiveness, bolstered safety and heightened user engagement across diverse exercise modalities. Yet, it is imperative to remain cognizant of and address associated challenges: the precision of sensors, cost considerations, user receptiveness, system design intricacies and ensuring the sanctity of data privacy. The incorporation of AI and machine learning algorithms, alongside other emerging technologies such as AR, MR and haptic feedback, holds great potential to further enrich the training experience by establishing more realistic, engaging and interactive virtual environments. Ultimately, this systematic review is conducive to the expanding body of literature on the application of VR and sensor fusion technologies in physical training, offering valuable insights for future research and practical applications. The persistent development and refinement of sensor fusion-based VR systems will undoubtedly lead to groundbreaking advancements in the field of physical training, benefiting both individuals and the wider society.

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摘要: In the modern era of sports training, the synergy between motion capture and Virtual Reality (VR) offers an innovative approach to enhancing training precision. This systematic review delves into the application of motion capture within VR for sports training, highlighting its transformative potential. Through a comprehensive literature search, we examined the myriad applications, from physical conditioning enhancements to accelerated rehabilitation processes. Our findings underscore the capability of real-time feedback, immersive training environments, and tailored regimes that this fusion provides. However, despite its promise, challenges such as hardware constraints, data processing complexities, and interaction interface limitations persist. Future trajectories indicate an increasing influence of AI and deep learning, promising more sophisticated hardware and a broader spectrum of applications, including niche sports disciplines. The review concludes with an emphasis on the wider societal implications, suggesting a shift towards a holistic athlete well-being approach.

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Systematic review of motion capture in virtual reality: Enhancing the precision of sports training

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Abstract. In the modern era of sports training, the synergy between motion capture and Virtual Reality (VR) offers an innovative approach to enhancing training precision. This systematic review delves into the application of motion capture within VR for sports training, highlighting its transformative potential. Through a comprehensive literature search, we examined the myriad applications, from physical conditioning enhancements to accelerated rehabilitation processes. Our findings underscore the capability of real-time feedback, immersive training environments, and tailored regimes that this fusion provides. However, despite its promise, challenges such as hardware constraints, data processing complexities, and interaction interface limitations persist. Future trajectories indicate an increasing influence of AI and deep learning, promising more sophisticated hardware and a broader spectrum of applications, including niche sports disciplines. The review concludes with an emphasis on the wider societal implications, suggesting a shift towards a holistic athlete well-being approach.

Keywords: Virtual reality, motion Capture, sports training, immersive experience, real-time feedback, injury prevention

1. Introduction

Sports training, at its core, encapsulates the systematic and purposeful practice aimed at honing athletic skills and improving physical performance [31,69]. While the primary objective has always been to enhance athletic prowess, sports training holds broader implications. It plays a pivotal role in injury prevention [26], ensuring athletes adopt correct techniques and postures that reduce the risk of strains or trauma. Beyond the realm of professional sports, training has profound effects on improving general life quality [104]. Engaging in regular physical activity bolsters health, augments mental well-being, and fosters discipline [76,103]. Moreover, foundational training serves as a cornerstone, preparing individuals for more rigorous, high-intensity workouts and competitions [10]. Over the decades,

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sports training methodologies have undergone significant evolution. Traditional training approaches, while effective, often lacked precision and real-time feedback. Enter VR – a technological marvel that has reshaped numerous industries, including sports training. VR offers an immersive experience, plunging athletes into simulated environments that closely mimic real-world scenarios [59]. This immersive nature facilitates better spatial awareness [62], decision-making [83], and technique refinement. Furthermore, the symbiotic relationship between VR and sports training is accentuated by the real-time feedback provided through VR systems [42]. Athletes can instantly receive insights into their performance, make necessary adjustments, and consequently enhance their training efficiency.

As sports training continually strives for precision, the integration of motion capture within VR has emerged as a game-changer [14]. Motion capture, often colloquially termed as 'mocap', involves recording the movement of objects or people [58]. In the context of sports training, it translates to capturing the intricate nuances of an athlete's movement, posture, and technique [65]. What makes motion capture indispensable in VR-enhanced sports training is its capability to provide immediate feedback [118]. Traditionally, athletes would rely on subsequent video reviews or coach observations to refine their techniques. With mocap integrated into VR, athletes receive instantaneous feedback on their posture and performance [100]. This real-time data allows them to make on-the-spot corrections, facilitating a more efficient and effective training session. Moreover, the granularity of data captured by mocap systems offers insights that might be imperceptible to the human eye [33]. From the angle of a tennis serve to the slight tilt in a sprinter's posture, every minute detail is captured, analyzed, and presented to the athlete [49,85]. This level of detail fosters a deeper understanding of one's performance, highlighting areas of excellence and pinpointing avenues for improvement. In essence, the fusion of motion capture with VR elevates sports training to unprecedented heights [77,95]. It merges the tangible realm of physical performance with the analytical prowess of technology, ensuring athletes are equipped with comprehensive insights to refine and perfect their skills.

The primary objective of this systematic review is to delve deep into the intersection of motion capture technology, virtual reality, and sports training. As technology continually reshapes the landscape of sports training, understanding its nuanced implications becomes imperative. This review aims to elucidate the transformative potential of integrating motion capture with VR, emphasizing how it enhances the precision of sports training. Our contribution to the academic and athletic communities is multifaceted. We offer a comprehensive synthesis of existing literature, bridging the gap between technology and athletic training. This review also sheds light on the current challenges and future prospects, serving as a roadmap for researchers and practitioners alike. Furthermore, by highlighting practical applications and real-world implications, this article aims to spur further innovation and exploration in the domain.

In Section 2, we delve deep into the evolution of both VR and motion capture technologies, underscoring their convergence and significance in sports training. Section 3 elucidates our meticulous approach to the literature, detailing our search strategy, study selection criteria, and data extraction methods as per the PRISMA guidelines. In Section 4, we present the tangible applications of motion capture-based VR across various facets of sports training, ranging from fitness and physical conditioning to rehabilitation and psychological training. Section 5 is dedicated to discussing the present challenges faced in integrating motion capture with VR, along with a projection of potential future trends and technological advancements. Conclusively, Section 6 encapsulates the key findings of this review, emphasizing its implications for subsequent research and real-world applications in sports training.

2. Motion capture in virtual reality

2.1. Development and key technologies of VR

VR has traversed a long journey since its conceptualization. Initially perceived as a mere digital novelty, VR has matured into an influential technological force shaping various industries, notably sports training [44]. The inception of VR can be traced back to the early 1960s with the creation of the Sensorama, a mechanical device offering a multi-sensory experience [9]. This was followed by the first HMD system, 'The Sword of Damocles', developed by Ivan Sutherland and Bob Sproull in 1968 [98]. With the advent of computer technology in the 1980s, VR saw significant advancements. Systems like the Virtual Environment Workstation Project by NASA paved the way for the more sophisticated VR systems we know today [57]. The 1990s and 2000s were marked by the proliferation of VR in gaming, with companies like Sega and Nintendo dabbling in VR gaming platforms. However, it wasn't until the 2010s, with the launch of Oculus Rift, that VR truly entered the mainstream market [24]. This period marked a rapid evolution in VR hardware and software. The development of low-latency HMDs, high-resolution displays, and powerful graphics processing units (GPUs) has made VR experiences more realistic and immersive.

Beyond hardware, software innovations have played a pivotal role. Platforms like SteamVR [19], Oculus Home [41], and PlayStation VR [39] have provided a plethora of content for users. VR's scope has expanded beyond gaming to sectors like healthcare, education, and, notably, sports training. Concurrent technological advancements, such as augmented reality (AR) and mixed reality (MR), have further broadened the horizons of immersive technologies [46,80]. Tools like Microsoft's HoloLens combine real and virtual worlds, offering a hybrid experience [67].

2.2. *Evolution of motion capture technology*

The realm of motion capture has witnessed a transformative journey, evolving from rudimentary tracking techniques to the sophisticated technologies we observe today. The precision and detail these technologies offer have been instrumental in enhancing various domains, particularly sports training in the context of Virtual Reality [88,90].

The inception of motion capture revolved around basic sensor technologies. Reflective markers were placed on key points of an individual's body, and cameras would track their movement based on the reflection of light from these markers. Magnetic field sensors [2], another early technology, gauged the movement of body parts by interpreting alterations in magnetic fields. Though revolutionary at the time, these methods had limitations, particularly in terms of accuracy and the range of motion that could be captured.

The next wave of innovation was ushered in with optical systems [121]. These systems employed multiple cameras placed at various angles to track markers on the body. The triangulation of data from these cameras resulted in more accurate and comprehensive motion capture. This method became a favorite in both the film industry and sports biomechanics due to its precision.

The introduction of depth cameras marked a significant leap [113]. Tools like Microsoft's Kinect brought about the possibility of capturing the entire body's motion without necessitating markers. Using infrared technology, Kinect mapped the depth and contours of objects, enabling the tracking of human movements with surprising accuracy [37]. This technology democratized motion capture, making it more accessible and straightforward.

As technology advanced, the focus shifted to capturing more nuanced movements, leading to the development of wearable devices, such as rings that track finger motion [1,120]. Gloves embedded with sensors could capture intricate hand movements, and full-body suits offered detailed data on body dynamics. These wearable devices, while offering detailed insights, also ensured that the natural movement of the user was not hampered [93,94]. For example, TSai et al. [100] explored a VR-based basketball training system enhanced with vibrotactile gloves to simulate real-world ball interactions. Although haptic feedback did not significantly impact passing reaction time, participants felt the gloves enhanced their passing and catching experience.

The latest in motion capture evolution is the fusion of data from various sources [109]. Combining data from optical systems, wearables, and depth cameras allow for a holistic view of movement. Advanced algorithms and software tools enable the synthesis of this data, providing insights that are both detailed and comprehensive.

3. Material and methods

The literature search and selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [61]. This ensured a comprehensive and unbiased review of motion capture in virtual reality for sports training. (Fig. 1).

3.1. *Literature search strategy*

The literature search was conducted across five major databases: Scopus, Web of Science, PsycINFO, ScienceDirect, IEEE Xplore, Embase, and PubMed. The search leveraged a combination of keywords or terms such as "virtual reality", "motion capture", "track*", "sports", "fitness", "decision making", "basketball", "table tennis", "soccer",

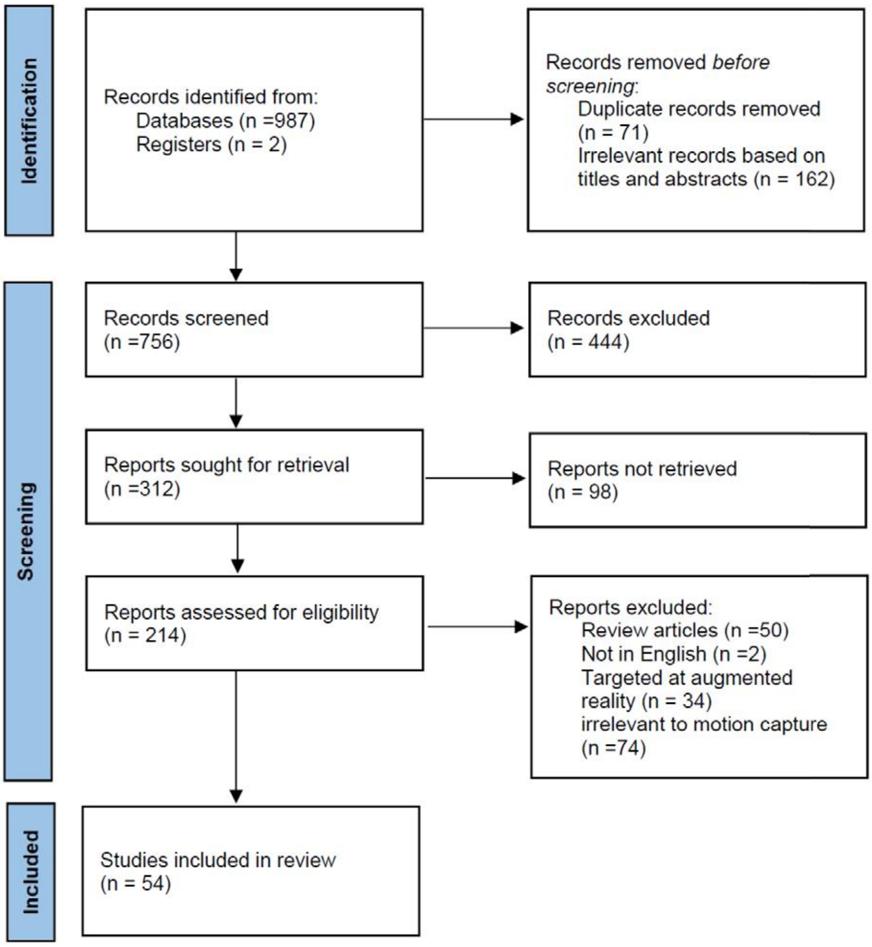

Fig. 1. Literature review process.

"rowing", "skiing", "running", "archery", "team", "collaboration", and "rehabilitation". Emphasis was placed on articles published from January 2018 to October 2023. This period was chosen because of the rapid advancements in both virtual reality and motion capture technologies in the last five years, rendering the insights from this timeframe particularly relevant and current.

3.2. Study selection criteria

Selected articles had to meet certain criteria to ensure relevance and quality. Firstly, only articles were considered, and they had to be published in English. Furthermore, the scope was narrowed down to those articles which were intertwined with virtual reality, motion capture technologies, and their application in sports training.

An initial search yielded 987 studies. After an initial screening, which involved removing duplicates and articles that were deemed irrelevant based on titles and abstracts, 756 studies remained. A more in-depth assessment of the full texts of these articles resulted in further refinement, with 214 articles assessed for their detailed relevance. Ultimately, 54 studies met all the criteria and were included in this systematic review.

3.3. Data extraction

We utilized the Cochrane Risk of Bias tool [5] to assess the quality of the studies incorporated in our analysis. This tool evaluates the potential bias in various aspects, encompassing reporting bias, selection bias, detection bias, attrition bias, performance bias, and other potential sources of bias. For the final set of 54 studies, key information was extracted. This encompassed aspects like the study design, sample size, and primary findings, especially those highlighting the applications in sports training. Data from these studies were qualitatively synthesized, allowing for the identification of overarching themes, potential benefits, challenges, and prospects of motion capture-based VR in sports training.

4. Practical applications of motion capture based VR in sports training

In today's rapidly evolving digital age, the confluence of motion capture and VR has carved out novel frontiers in the domain of sports training. This powerful merger elevates the sports training landscape by offering a unique blend of precision, interactivity, and adaptability. As sports training transcends beyond mere physical prowess to a holistic amalgamation of physicality, cognition, strategy, and recovery, leveraging innovative tools becomes paramount. In this section, we unravel the multifaceted applications of motion-capture-based VR in sports training, exploring how it resonates across diverse dimensions of the athletic experience.

4.1. Fitness and physical conditioning

In the sprawling canvas of sports training, physical conditioning stands tall as a cornerstone, functioning as a linchpin that binds together an athlete's endurance, strength, and flexibility. It's imperative to stress the convergence of VR and motion capture in the domain of fitness and physical conditioning as it has not only revolutionized traditional methodologies but has also amplified the granularity of feedback athletes receive. Harnessing the immersive capabilities of VR combined with the precision of motion capture can shape training regimens that are tailored, responsive, and deeply immersive, offering athletes a chance to engage with their regimen in unprecedented ways. Table 1 summarizes the literature review findings in fitness and physical conditioning.

Immersive VR systems and Xbox Kinect training have shown promising results in improving aerobic activity, muscle strength, and overall quality of life, addressing challenges like cybersickness and ensuring alignment with sports science guidelines is critical. Feodoroff et al. [30] examined the effects of an immersive VR training system and found that it elicited moderate aerobic and muscle-strengthening activity in young adults, with most participants enjoying the experience (Fig. 2). However, dropouts due to cybersickness and prior injuries underscore the importance of further technological enhancements and adherence to sport and exercise science guidelines in future VR training systems. In [8], the integration of Xbox Kinect training was found to considerably boost cardiopulmonary fitness, muscle robustness, lean body mass, and overall life quality. The heightened sense of pleasure reported by participants from this approach further accentuates its potential as an impactful and engaging apparatus for physical rehabilitation. In a comparative study focusing on the repercussions of Xbox Kinect VR training versus traditional workout regimes for individuals who suffered a stroke, both methodologies exhibited enhanced balance and functional autonomy [97]. Intriguingly, those in the Kinect cohort manifested pronounced improvements in functional movement, trunk synchronization, and autonomy.

The efficacy of VR balance training is influenced by the type of control sensors used. Vries et al. [22] investigated the balance challenges posed by two similar skiing VR games, Wiiski and Kinski (Kinect sensor), in terms of center of mass (COM) movements relative to Functional Limits of Stability. Findings revealed that Kinski provided a more challenging balance experience than Wiiski, suggesting that the type of control sensors and their settings significantly impact the balance training efficacy of VR games. For populations with specific health concerns, like postmenopausal women with osteoporosis, VR training (VRT) equipped with body-tracking can offer superior improvements in dynamic task balance compared to conventional methods. In a study involving postmenopausal women with osteoporosis [81], virtual reality training (VRT) utilizing Xbox 360 games and a Kinect camera, which tracks the participant's body position to provide real-time feedback, was evaluated for its effects on functional balance. The results showed that while both VRT and conventional training methods improved balance in dynamic tasks, the VRT, with its body-tracking capabilities, was notably more effective in enhancing control over weight-shifting tasks. Based on a VR-skateboarding scenario developed in Unity3D and displayed on HTC VIVE headsets (in Fig. 3), participants' biomechanics during skateboarding were compared to walking [45]. Using motion

Table 1
Summary of literature review findings in fitness and physical conditioning

References	Fitness type	Study design	Participants	VR setup	Performance measure
Feodoroff et al. [30]	Aerobic physical activity; muscle-strengthening activities	Cross-sectional experiment	33 participants	Icaros system; HMD; Heart rate monitor	Muscle activity; heart rate; rate of perceived exertion
Basha et al. [8]	Xbox Kinect training	Randomized controlled trial	40 participants	Xbox Kinect-based virtual reality system	VO2peak; muscle strength; lean mass quality of life; physical activity enjoyment
Sultan et al. [97]	Exergaming by Xbox Kinect	Parallel double-blind randomized control trial	41 individuals	Xbox Kinect	Functional mobility; independence; trunk coordination extension
Vries et al. [22]	Balance training	Controlled trial	30 young adults; 30 healthy older adults	Wii Balance board; Kinect sensor	Functional limits of stability
Rezaei et al. [81]	Performance-based limits of stability; curve tracking; sit-to-stand; turning	Preliminary single-blind, randomized controlled trial	12 postmenopausal women	Xbox 360 games; a kinect camera	Center of pressure
Kantha et al. [45]	VR-skateboarding and walking	Biomechanical experiment	20 participants	A split-belt treadmill; HMD; a skateboard	Trunk flexion angles; muscle activity; hip flexion
Pourazar et al. [72]	Reaction time training	Randomized controlled trial	30 boys	Xbox 360 Kinect	Simple reaction time; discriminative reaction time
Rutkowski et al. [84]	Reaction time training	Pilot study	14 individuals	HTC Vive Pro headset; a connected laptop	Reaction time

Fig. 2. (A) Torso–arm angle measurement using protractor, (B) Icaros device, (C) participant being familiarized with the device, (D) upper-to-lower limb angle measurement using protractor. [30].

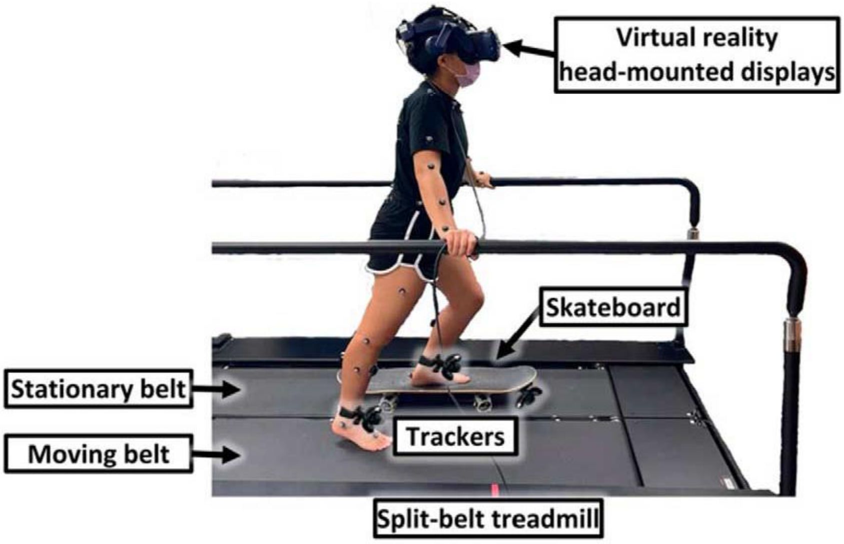

Fig. 3. An illustration of a virtual reality skateboarding system. [45].

trackers on participants' legs and skateboards, the study found that VR-skateboarding notably enhanced trunk and hip flexion, knee extensor muscle activity, and weight distribution on the supporting leg.

Virtual reality and motion capture integration offers revolutionary improvements in physical functions, including resistance, endurance, and reaction time. Through the integration of virtual reality and motion capture technologies, Wei et al. [108] developed an algorithm to enhance the shooting techniques of basketball players. Results indicate that this method, combined with resistance training, improved shooting percentages up to 14%, with height variations being a notable factor in the outcomes. [20] underscored the potential of VR in enhancing motivation and engagement in endurance exercises for patients with chronic respiratory diseases. The "Virtual Park" system, designed for cycle-ergometer training, demonstrated promising initial results in usability and acceptability, suggesting the feasibility of integrating VR into traditional respiratory rehabilitation regimens. Using Xbox 360 Kinect as the therapeutic VR device, Pourazar et al. [72] assessed the impact of VR on reaction times in children with cerebral palsy. The Kinect's real-time visual feedback and three-dimensional tracking capabilities facilitated significant improvements in both simple and discriminative reaction times post-intervention. The results underscore the potential of Kinect-based VR in enhancing rehabilitation for children with cerebral palsy. In [84], the VR setup tracked the movement of controllers and goggles through two sensors, and participants engaged with music tracks, slicing color-coded blocks with virtual swords in rhythm, also dodging obstacles to engage the entire body. This VR-based intervention demonstrated potential in accelerating the proficiency of young musicians in mastering instruments.

In the realm of fitness and physical conditioning, leveraging VR and motion capture offers transformative potential. However, challenges persist. Users often grapple with cybersickness, leading to higher dropout rates in VR experiences. The efficacy of balance training is influenced by sensor configurations, demanding precision in settings to achieve desired outcomes. Moreover, when targeting specific demographics, such as postmenopausal women, the need for tailored VR exercises becomes paramount. Additionally, device-specific limitations, like those observed in Kinect, may constrain their broad application.

4.2. *Cognitive and mental training*

At the intersection of sports and cognition lies an intricate web of decision-making, anticipation, strategy formulation, and psychological resilience [106]. While physical prowess remains paramount, the cognitive and mental faculties of an athlete often determine the outcome in high-stakes scenarios. The advent of VR and motion captute technologies has ushered in a new age of cognitive and mental training, allowing for unparalleled immersion, feedback, and adaptability. Their combination on sports training stretch beyond mere physical adaptations, diving deep

Table 2
Summary of literature review findings in cognitive and mental training

References	Mental training type	Study design	Participants	VR setup	Performance measure
Romeas et al. [83]	3D multiple object tracking	3D-MOT trial	57 participants	NeuroTracker system	Speed thresholds; success rate
Tsai et al. [101]	Decision-making training	Between-subject experiment	45 basketball players	An IMU-based full-body motion capture suit; HMD	Test score; the average duration of decision time
Kittel et al. [47]	Decision-making training	Randomised control trial	32 Amateur Australian football umpires	360° video camera; 360°VR	Psychological fidelity, engagement
Kocur et al. [48]	Psychological resilience	A real-world experiment	24 participants	Game engine Unity3D; HTC Vive tracker	Heart rate; perceived exertion; pedaling frequency; distance; body ownership; self-perceived fitness; user identification

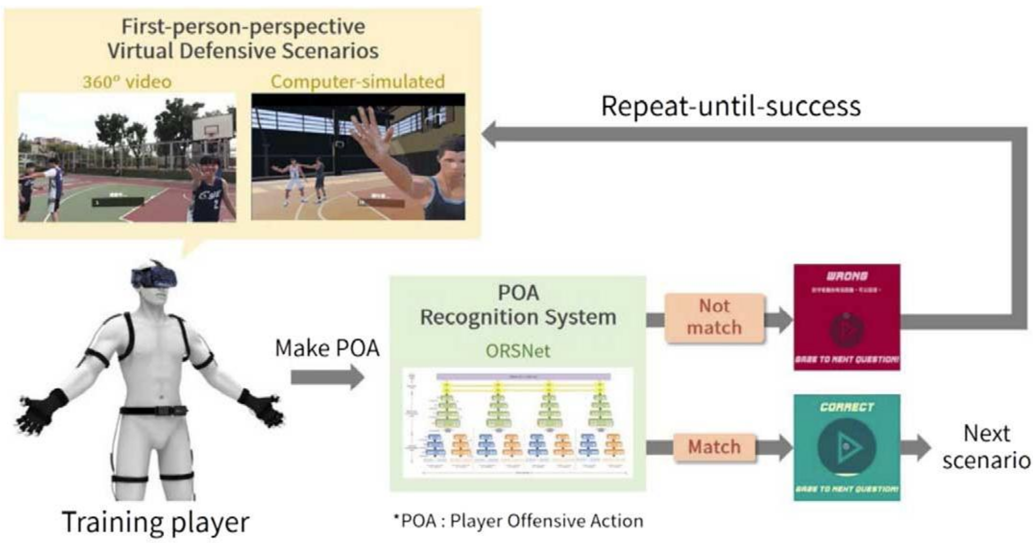

Fig. 4. System framework. [101].

into the realms of neuroplasticity, perception, and emotional regulation. Table 2 summarizes the literature review findings in cognitive and mental training.

Virtual Reality facilitates enhanced decision-making and cognitive performance in sports scenarios. Using video simulations boosts decision-making in invasion sports, but its real-world transferability and generalizability have been unclear. A study with varsity basketball players found that while both computer screen (CS) and VR training enhanced decision-making for trained plays, only VR training led to generalized improvements for untrained scenarios [66]. Delving deeper into the intricacies of VR, Romeas et al. [83] investigated a virtual training paradigm combining three-dimensional multiple object tracking (3D-MOT) with either motor or perceptual sport decision-making tasks. Results indicated dual-task training improved performance in both areas, but 3D-MOT training was more effective when sequentially done before a motor decision-making task rather than simultaneously. Meanwhile, in the basketball arena, Tsai et al. [101] proposed a VR-based basketball offensive decision-making training tool that allows intuitive user interaction via a motion capture suit, offering feedback on user decisions in varied virtual defensive setups crafted by experts. The system's efficacy was contrasted with traditional tactics board training, and its system is as shown in Fig. 4. In a contrasting sporting milieu, Australian football, Kittel et al. [47] compared the efficacy of 360° Virtual Reality (360°VR) and traditional match broadcast footage for decision-making training in amateur Australian football umpires. While the 360°VR showed notable advantages over the control group in retention tests, overall improvements were inconclusive. However, results showed that participants favored 360°VR for its enhanced psychological fidelity, engagement, and relevance over traditional footage.

Virtual Reality offers transformative experiences for athletes by manipulating stressors and perceptions, promising enhanced performance and psychological resilience. Kocur et al. [48] examined the influence of an avatar's athleticism on users' physiological responses and perceived effort during VR cycling exercises. Results revealed that more athletic avatars led to significant changes in users' heart rate and their sense of exertion, suggesting potential interplays between virtual embodiment and physical exercise perceptions. Broadening the application horizon of VR beyond traditional athletic training, Liao et al. [4] examined the efficacy of VR integrated with physical and cognitive exercises to enhance dual-task gait performance and executive function in older adults with mild cognitive impairment (MCI). Using the Kinect system, the VR training adopted a range of physical activities, such as Tai Chi and functional tasks like window cleaning. Findings indicated that the VR-based approach, offering immediate visual and auditory feedback, showed marked improvements in executive function and dual-task gait performance compared to traditional combined training methods.

In the arena of cognitive and mental training, the integration of VR and motion capture technologies has been instrumental in amplifying decision-making, anticipation, and psychological resilience of athletes. The immersive environments of VR, combined with the real-time feedback of motion capture, offer athletes a nuanced training platform. Studies have indicated that while video simulations can enhance decision-making in sports, the immersive nature of VR ensures a broader application, including untrained scenarios. Furthermore, VR's potential in manipulating athletes' perceptions, such as using athletic avatars, can influence physiological responses and perceived effort levels, hinting at a profound link between virtual embodiment and physical training. Additionally, VR's application isn't limited to elite athletes. Its use in improving cognitive functions in older adults, by integrating physical and cognitive exercises, showcases its potential in a broader spectrum of applications. However, despite these advancements, ensuring the transferability of skills from VR to real-world scenarios remains a challenge.

4.3. Sport-specific training scenarios

Each sport offers its unique challenges, intricacies, and subtleties that require specialized training tools and techniques [79,92]. Modern technology, especially the seamless integration of motion capture with VR, is poised to redefine the training landscape across different sports. Table 3 summarizes the literature review findings in sport-specific training scenarios.

Basketball, a game requiring accuracy, footwork, and coordination, has witnessed advancements in training methodologies, among which the precision offered by motion capture in VR is invaluable. This year, Liu et al. [52] presented an AR/VR-based motion capture approach to enhance college basketball training. By integrating skeletal data and employing the LSTM algorithm, the method achieved recognition rates of 85% for "shooting" and "defense" actions, and over 93% for other movements. With motion capture equipment, the action recognition time was reduced to about 210 ms, a 100 ms improvement over conventional tools. In a study examining basketball shooting in a virtual environment (Fig. 5), success rates and kinematics were tracked across different scales to assess player expertise and perceptual awareness of basket distance [89]. While success rates and ball kinematics reflected expertise and distance manipulation, body kinematics only indicated player expertise and gender, underscoring the nuances of using VR for sports training.

Harnessing motion recognition technology, modern solutions are reshaping the landscape of sport-specific training, with table tennis serving as a pertinent example. For table tennis beginners in China, proper technical guidance is often not available, leading to incorrect techniques and potential injuries. Addressing the limitations of traditional teaching methods, Han [40] introduced an intelligent system that uses motion recognition technology, specifically through inertial sensors at skeletal points, to recognize and classify human table tennis movements. The proposed system not only aids in motion correction but also proves valuable for technical analysis and tactical planning in the sport. Similarly, in response to the push for enhanced physical education in schools, Shen [85] introduced a table tennis technical action evaluation system developed using mixed motion capture technology, specifically leveraging Microsoft Kinect2.0. This system facilitates technical guidance and evaluation for table tennis trainers, enhancing

Table 3
Summary of literature review findings in sport-specific training scenarios

References	Sports type	Study design	Participants	VR setup	Performance measure
Liu et al. [52]	Basketball training	Test experiment	10 personnel	Kinect sensors	Accuracy; recall; response time
Soltani et al. [89]	Basketball training	Pilot study	12 experienced and 10 novice basketball players	A realistic virtual basketball court; stereoscopic glasses	Success-rate; ball and body kinematics
Shen [85]	Table tennis training	Pilot study	20 secondary players and 20 outstanding players	Kinect2.0 motion capture equipment	Euler distance; degree of participation
Chung et al. [18]	Soccer training	Case study	A trial user	A wearable motion capture device with 24 nodes; Vive's HMD	Kinect energy
Wood et al. [110]	Soccer training	Randomised control trial	17 professional soccer players, 17 academy players, 17 novice players	A HTC Vive Pro head-mounted display; 4 detachable HTC Tracker 2.0 sensors	Passing accuracy, composure, reaction time, and adaptability
Arndt et al. [6]	Rowing training	Pilot study	16 participants	Augletics Eight2; a HTC Vive headset	Stroke length; recovery; rhythm; consistency; movement
Wu et al. [111]	Skiing training	Controlled experiment	81 participants	VR ski training simulator	Ankle rotation
Ono et al. [64]	Skiing training	Pilot study	16 participants	HTC Vive Pro; Pro Ski-Simulator	Proficiency level
Perrin et al. [70]	Running training	Randomised control trial	17 healthy individuals	HMD devices; a handheld Vive controller	Error between actual and perceived locomotor speed
Purnomo et al. [74]	Archery training	Pilot study	10 participants	Oculus Rift S	Navigation, interaction, application process and satisfaction

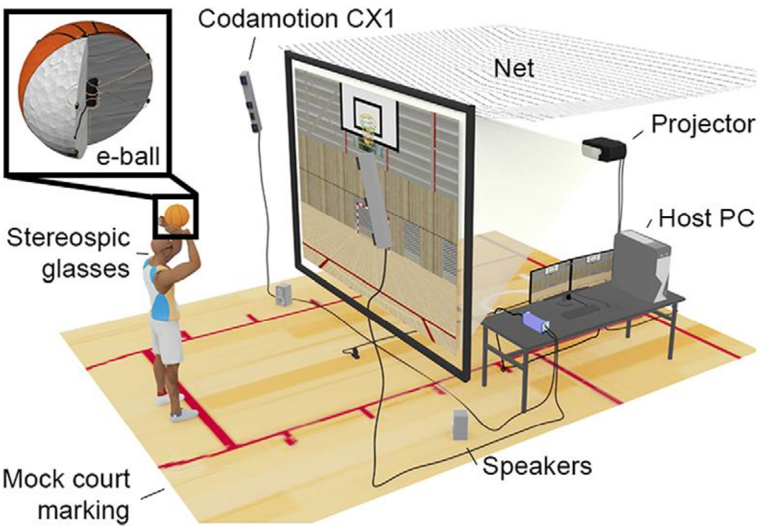

Fig. 5. Arrangement of the hardware components of the basketball throwing simulator installed in a 6 m long × 5 m high room. [89].

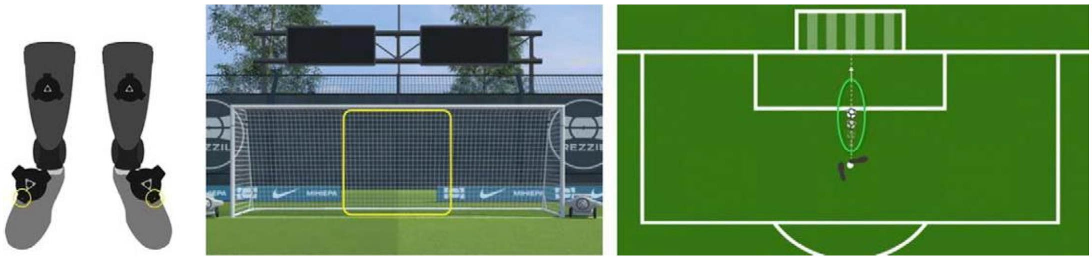

Fig. 6. Showing the sensors placed on the shin guards and feet of the players (left), and the accuracy (center) and speed (right) calibration drills. [110].

self-learning and technique assessment. The use of Kinect2.0 ensures efficient data capture and processing, making it practical and feasible for widespread adoption, ultimately advancing the integration of sports with computer technology.

Modern advancements in immersive VR gaming also spotlight the innovative use of Head Mounted Displays (HMD) and motion capture methods for soccer training. Chung et al. [18] highlighted the rise of Head Mounted Displays (HMD) for immersive virtual reality gaming. While many interaction devices, like Leap Motion and marker-based devices, have their constraints, this research introduced a wearable motion capture method, which tracked movement despite obstructions, and tested its application in a VR soccer game – marking a pioneering effort in the field. Wood et al. [110] assessed the construct validity of a soccer-centric VR simulator, MiHiepa Sports Rezzil, by testing its ability to differentiate skill levels among professional, academy, and novice players. The MiHiepa Sports Rezzil VR platform utilizes the HTC Vive Pro, a high-resolution head-mounted display, complemented by HTC Tracker 2.0 sensors affixed to players' shoes and shin guards (Fig. 6). These trackers, synchronized with the HTC Lighthouse 2.0 system, enable precise motion capture, providing a detailed and responsive simulation experience for users during soccer training drills.

In rowing, where rhythm and technique are paramount, VR combined with sensor feedback offers a novel approach to training. In a pilot study exploring the integration of VR with sensor feedback, athletes used a stationary rowing machine within a VR environment, with the machine's sensors providing real-time movement data to the VR display [6]. Initial findings suggest that this VR setup not only enhanced the athletes' training experience but also positively impacted their rowing performance compared to traditional training methods. To facilitate athlete training and offer non-athletes a gamified rowing experience, Shoib et al. [87] focused on creating a VR rowing simulation. By integrating the rower machine with trackers, the simulation captures real-world rowing motions, where one ergometer pull equates to a single stroke in the game, allowing for realistic speed and distance replication. At the same year, In [102], a novel interactive system was developed over three design iterations that pairs the dynamic ergometer (RP3) with the HTC Vive platform, augmented with three location trackers. This system offers enhanced opportunities for learning and refining rowing techniques, potentially reducing injury risks associated with the learning curve.

In ski training, virtual reality's integration has proven transformative, enabling a more nuanced and feedback-driven approach to mastering the sport's nuances. A VR-based ski training platform was developed, using an indoor simulator enhanced by two trackers to replicate ski movements on a virtual slope [111]. By studying the efficacy of visual cues and feedback, the system offers insights into leveraging pro-skier motion patterns to bolster ski training, shedding light on the potential and constraints of such VR ski training tools. Based on the above research, Ono et al. [64] introduced a VR support system to train novice skiers, emphasizing weight-shifting techniques based on prior findings from deep learning analyses. Through real-time feedback on users' weight-shifting patterns, the system has been shown to significantly aid participants in mastering this crucial skiing skill.

In the field running and walking, the calibration of perceived motion in virtual reality remains a crucial consideration. Using an enactive approach with the HTC Vive system, Perrin and his colleagues [70] investigated the accuracy of perceived locomotion speed in virtual environments (VE) during treadmill activities. While the overall average showed accurate speed perception, individual discrepancies varied, with some consistently overestimating or underestimating. Consequently, the paper suggests personalized adjustments instead of general correction for VR

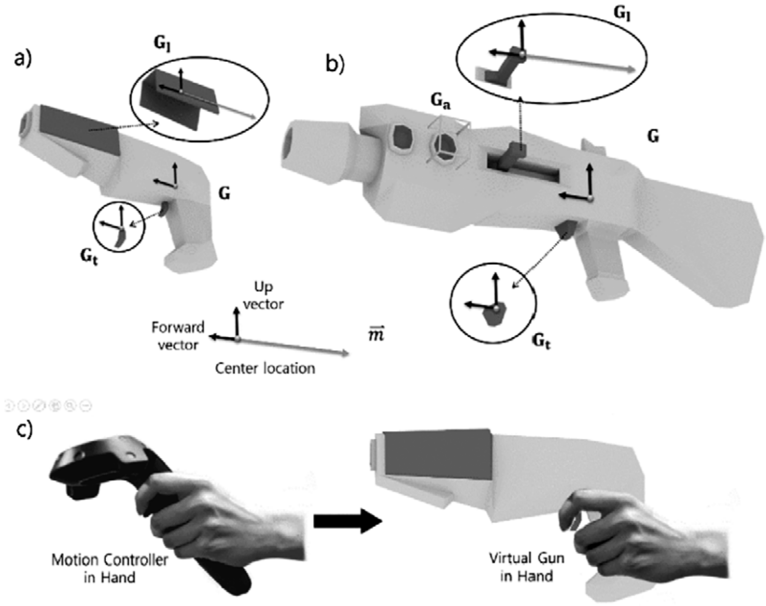

Fig. 7. Proposed gun interface solutions, consisting of three mesh objects and an additional attachment: (a) pistol interface, (b) machine-gun interface, and (c) correspondence of the motion controller with a virtual gun interface. [50].

locomotion applications to ensure authentic speed perception. Krasnyanskiy et al. [49] explored crafting a control system for a running platform in virtual reality, aiming for adaptive speed adjustments based on user behavior to heighten immersion and comfort. Leveraging a unidirectional treadmill and VR trackers, new control functions were devised, tested, and assessed, which minimized users' deviations from a starting position, mitigating oscillation and inertia impacts.

From archery to first-person shooters and even Para-Badminton, the integration of motion capture and VR offers unparalleled realism and potential therapeutic applications. Aprial et al. [3] delved into the integration of motion capture with VR in creating a more immersive archery game experience. By harnessing the capabilities of both technologies, they attempted to enhance realism in archery games, positioning them not only as entertainment but also as potential cognitive development tools. On the basis of above study, a VR simulator tailored for conventional archery training was invented, leveraging the Oculus Rift S to mimic authentic archery movements [74]. The simulator's effectiveness was evaluated based on navigation, interaction, application processes, and user satisfaction. Apart from that, an innovative system for heightened realism in VR first-person shooter games was proposed, utilizing motion controllers to track player's hand and head movements [50]. By establishing a seamless correspondence between the physical and virtual realms, they offered refined player-gun interactions (Fig. 7), verified using a VR FPS demo and a gun template, demonstrating its potential applicability to other VR motion-controlled games. As far as Para-Badminton matches, researchers from the University of São Paulo, in collaboration with the State University of Campinas, created a nocel virtual reality game [32]. Designed to boost performance and mitigate neuropathic pain in athletes with Spinal Cord Injury, this endeavor leverages the Unity 3D game engine and Leap Motion hardware.

To sum up, the amalgamation of VR with motion capture and sensor technologies is ushering in a new epoch in sports training. It promises more effective training methodologies, personalized feedback mechanisms, and realistic simulations, potentially reshaping the future of sports training across various domains. The ensuing sections will further delve into the underlying technological innovations driving these advancements and their broader implications for athletes and trainers alike.

4.4. Team collaboration and strategy

In the domain of team sports and collaborative endeavors, VR has come to the forefront as a versatile tool for assessing and training players. Table 4 summarizes the literature review findings in team collaboration and strategy.

Table 4
Summary of literature review findings in team collaboration and strategy

References	Team collaboration	Study design	Participants	VR setup	Performance measure
Vu et al. [105]	Multiple soccer players training	Pilot trials	32 volunteers	HTC VIVE EYE PRO	Visual tracking performance; gaze activity; search rate
Fan et al. [27]	Team training	Randomised experiment	6 participants	HMD; VoIP headset	Simulated training performance
Mas et al. [56]	Spatial navigation training	Proof of concept	N/A	Indy, a virtual reality system	N/A
Gugen-heimer et al. [36]	Co-located social interactions	Exploratory user study	16 participants	FaceDisplay, a mobile VR HMD	Enjoyment; social interaction; presence; emotional state
Chen et al. [16]	Collaborative VR for learning	Pilot study	30 undergraduate students	Oculus CV1 HMD; Oculus Touch	Task performance; engagement level; collaboration patterns

Vu et al. [105] utilized Virtual Reality to investigate the visual tracking capabilities of soccer players compared to non-players in tracking moving virtual characters. While soccer players exhibited superior tracking abilities, their expertise did not provide an advantage in scenarios mimicking real game trajectories. Bonfert et al. [27] emphasized the integration of body area networks (BANs) with VR to enhance soldier-based team training, compensating for spatial constraints in traditional facilities. Experiments, as indicated by the tracking of arm movements in a T-pose, demonstrate the system's proficiency in directly monitoring motion trajectories.

To enhance spatial navigation skills essential for complex industrial settings, Mas et al. [56] introduced "Indy," a virtual reality-based collaborative treasure hunting game. Similarly, Wu et al. [112] developed "Sky Classroom," a global project-based course emphasizing collaborative building design. This avatar-driven tool, evolving from desktop to immersive virtual reality versions, enhances collaboration by immersing users within the BIM model.

The momentum of VR applications in team collaboration and strategy has spilled over into engineering and industrial sectors as well. To streamline lifecycle engineering tasks, a multi-user VR training system was proposed, meticulously integrated with virtual factories, focusing on wind turbine assembly [115]. Preliminary evaluations by experts highlighted the system's potential to revolutionize industrial training effectiveness and efficiency. "FaceDisplay" [36] is an innovative VR headset embedded with a depth camera and touch-sensitive screens, allowing bystanders to view and interact with the virtual realm experienced by the primary user. Initial applications and user studies suggested potential for enhancing co-located social interactions, challenging the prevailing HMD-centric design approach to be more inclusive of non-HMD users. As far as collaborative VR for learning, it was found that a shared view improved task performance and that side-by-side positioning optimized user experience [16]. Notably, users' movements were realistically mirrored in the VR space, as their heads and hands were tracked in 6 DoF by the Oculus Touch sensors, enabling accurate representation through avatars. To cope with the limitations of traditional VR systems, Ha et al. [38] developed a motion-capture-based VR collaboration tool, enhancing immersion by aligning users' real movements with their virtual avatars. The system adjusted the avatar's size for user-body congruence, with experiments indicating minimal height discrepancies, and successful remote collaboration trials involving multiple participants (Fig. 8).

VR is revolutionizing team sports and collaborative strategies, offering nuanced platforms for enhanced training. From evaluating soccer players' visual tracking to military spatial training, VR's scope is vast. The industrial sector, too, is embracing VR for spatial navigation and collaborative design. Innovations like "FaceDisplay" allow bystanders to participate in a user's virtual experience, broadening VR's inclusivity. As VR integrates with motion capture, it promises to reshape team collaboration across diverse fields.

4.5. *Rehabilitation and injury prevention*

As sports training continually seeks precision and optimization, there arises a profound need to safeguard the well-being of athletes and individuals who engage in physical activities. This safeguarding is twofold: ensuring

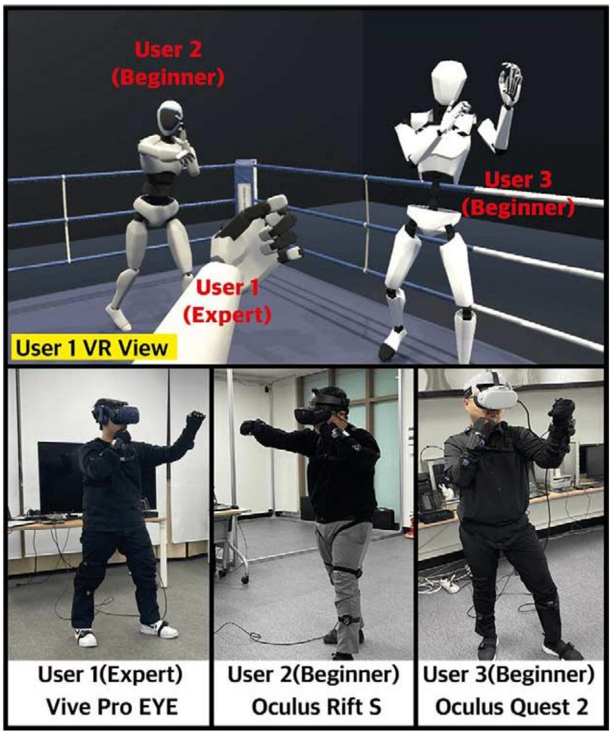

Fig. 8. Multi-remote collaboration test. [38].

efficient rehabilitation post-injury and preventing future occurrences. As injuries can range from minor strains to debilitating conditions, a holistic approach to recovery is essential. Not only does VR offer a dynamic and interactive platform that enhances patient engagement, but the precision offered by motion capture provides invaluable data that can be harnessed to tailor specific therapeutic interventions. Table 5 summarizes the literature review findings in rehabilitation and injury prevention.

VR has emerged as a groundbreaking tool in the realm of rehabilitation and injury prevention, offering tailored solutions to a spectrum of physical challenges, such as neck pain, shoulder rehabilitation, upper limb rehabilitation, and lower limb rehabilitation. In [60], a VR system was proposed, which utilized the Oculus Rift DK2 headset to motivate individuals with neck pain to adhere to prescribed exercises. By immersing users in a tailored exergame designed around their specific neck range of motion, the system not only promotes rehabilitative movement but also assesses neck flexibility. In shoulder rehabilitation monitoring, the Oculus Quest 2 [15] demonstrated a mean absolute error of 13.52 ± 6.57 mm for translational displacements at 500 mm from the head display in the x-direction, and a maximum error of $1.11 \pm 0.37°$ for 40° rotational movements around the z-axis. Given these results, the Oculus Quest 2 offers promise as an effective alternative to conventional motion tracking systems in rehabilitation scenarios. Bortone et al. [12] presented an immersive VR rehabilitation system with wearable haptics tailored for children with neuromotor challenges, as shown in Fig. 9. Initial trials with children affected by cerebral palsy and developmental dyspraxia indicate the system's adaptability to varying motor skills and its potential as a tool for kinematic assessment of motor functions. In [73], the effects of incorporating Nintendo Wii-based VR with conventional therapy were compared with conventional therapy on upper limb function in spinal cord injury patients, results after 4 weeks revealed comparable improvements in hand function for both groups. VR offers an engaging and interactive dimension to traditional rehabilitation, serving as a form of biofeedback and allowing patients to monitor daily performance progress. Zhang et al. [117] employed wearable TENG-based devices for detailed gait and waist motion analysis, aiding in lower-limb and waist rehabilitation, as shown in Fig. 10. By integrating these devices with virtual gaming, they enhanced immersion during rehabilitation sessions.

Table 5
Summary of literature review findings in rehabilitation and injury prevention

References	Rehabilitation type	Study design	Participants	VR setup	Performance measure
Mihajlovic et al.	Head-neck rehabilitation exercises	A user study	30 users aged 18–50	Oculus Rift DK2 VR headset	Mean tracking scor
Bortone et al.	Rehabilitation of upper limbs	Controlled trial	20 subjects	Two dedicated immersive SG and a Graphical User Interface (GUI)	Kinematic measurements
Prasad et al.	Rehabilitation of upper limbs	Pilot randomized controlled trial	22 patients	Nintendo Wii	Capabilities of upper extremity
Fang et al.	Sports rehabilitation	Pilot study	40 students in the first class and 45 in the second class	HMD	Excellence rate of the experimental class
Askin et al.	Upper extremity motor functions	Randomized controlled trial	40 chronic stroke patients	Xbox Kinect	Upper extremity (UE) Fugl-Meyer Assessment (FMA)
Shen et al.	Physical rehabilitation	Pilot study	10 healthy children and 4 children with TBIs	An HTC Vive VR headset and Vive controller	Engagement; user experience
Choi et al.	Upper-limb function rehabilitation	Randomized controlled trial	80 children with brain injury	Virtual reality rehabilitation system	Functional and kinematic assessments

Leveraging virtual scene position mapping focused on upper limb movements [28], a study on sports rehabilitation students showed significant improvements in practical test scores, with the experimental group outperforming the control by 24.2% in excellence and 12% in pass rates, suggesting that VR applications not only enhance practical skills but also pique learners' interest, with motor skills in virtual setups being transferable to real-world scenarios. Yan [114] delved into using virtual reality for sports rehabilitation, introducing an AR algorithm for dynamic target tracking in VSLAM and leveraging OpenPose for hand gesture recognition in patient training. Through Unity3D and Photon Server, a multi-user virtual training environment was created, notably improving tracking accuracy in areas like head positioning and leg movement based on users' perspectives in a motion capture system.

Moreover, evidence from a randomized trial underscored the advantages of amalgamating Kinect-based VR training with traditional physical therapy for chronic stroke patients [7]. The synergistic approach led to improvements in upper extremity motor functions and range of motion compared to exclusive physical therapy treatments. To elevate the motivation levels of stroke patients and make repetitive exercises less tedious, Dias et al. [25] introduced VR mini-games tailored for upper limb exercises. Though some challenges were encountered, such as sensor placement and game misalignment, these were addressed through methodical adjustments, underscoring the adaptability of VR in rehabilitation scenarios.

The growing integration of VR into cognitive rehabilitation demonstrates its promising potential, especially in children with traumatic brain injuries (TBI) and associated motor challenges. In 2020, a VR system tailored for cognitive rehabilitation was devised, targeting three core executive functions, in children with traumatic brain injuries [86]. While prior VR tools focused on physical rehabilitation, this innovative system, well-received in pilot testing, emphasizes cognitive recovery post-TBI in children. In a case study involving a young male with severe TBI, the Computer Assisted Rehabilitation Environment (CAREN) system – a virtual reality tool by MOTEK Medical featuring motion capture and a multi-faceted VR immersion experience – was employed alongside standard cognitive rehabilitation [21]. Notably, significant cognitive and motor improvements were observed only post-CAREN training, suggesting the potential efficacy of immersive VR in TBI cognitive rehabilitation. Choi et al. [17] explored the effectiveness of a wearable sensor-based virtual reality system in enhancing upper-limb function in children with brain injuries (Figrue 11). Results revealed that the VR group, which incorporated repetitive task-oriented games using wearable inertial sensors, showcased notably better upper-limb dexterity and daily activity performance than the conventional therapy group.

In rehabilitation and injury prevention, the blend of VR and motion capture offers personalized recovery pathways. While VR enhances engagement and offers tailored exercises, challenges persist in seamlessly integrating

Fig. 9. Overview of the proposed rehabilitation system with a close-up of the VE visualized through the HMD (Head Mounted Display), and of the two wearable haptic devices rendering contact forces. [12].

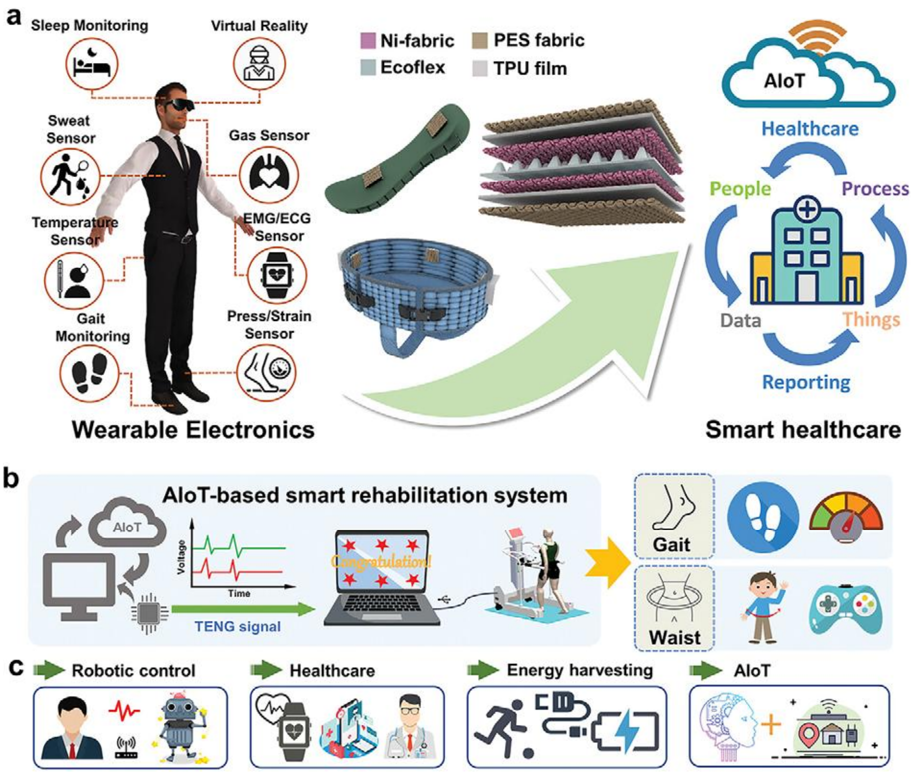

Fig. 10. Schematics of the AIoT-based smart healthcare. [117].

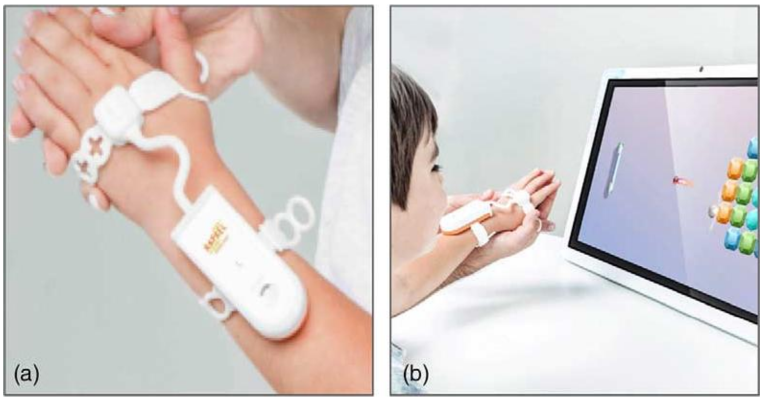

Fig. 11. Component of the virtual reality device developed for upper-limb rehabilitation in children with disabilities. [17].

it with traditional methods. Especially in cognitive rehabilitation post-traumatic injuries, ensuring real-world skill transfer and long-term efficacy from VR training remains pivotal. The synergy between VR and conventional approaches is crucial for optimal outcomes.

5. Challenges and future trends

5.1. Current challenges

The integration of motion capture within VR for sports training brings forth a new horizon of possibilities. However, it is not without its set of challenges that need to be addressed to harness its full potential.

The size and comfort of motion capture sensors remain a challenge, especially in sports that demand unrestrained movement [23]. In sports like long-jump, these sensors can potentially shift during performance, altering the data's accuracy. The durability of these sensors is crucial, especially when considering the vigorous movements in sports like boxing or martial arts. In terms of data processing, sports like gymnastics or ballet, where precision is paramount, require real-time, detailed feedback. This demands robust algorithms capable of instantaneous processing [51]. In sports that require immediate response, like fencing or tennis, latency can compromise the training's effectiveness.

A single motion capture session can generate gigabytes of data, especially when capturing detailed movements. This data volume exponentially increases in VR scenarios where environments are richly detailed and interactive. The transformation of raw sensor data into meaningful feedback requires complex algorithms [35]. These algorithms need to factor in individual athlete biomechanics, the sport's specific requirements, and potential environmental variables [43]. In sports training, a delay of even a few milliseconds in feedback can be the difference between a successful training session and a missed opportunity [29]. Ensuring that data processing and feedback provision happen in real-time, without noticeable latency, is a significant challenge.

Traditional VR interaction mechanisms, like hand controllers, may not always be feasible in high-intensity sports training [13]. Integrating voice commands [71], gaze tracking [68], or gesture recognition [34] can offer more natural interaction methods. However, ensuring their accuracy in dynamic training environments is challenging. Beyond interaction, how feedback is relayed to the athlete in VR is crucial. Visual or auditory cues need to be intuitive and non-distracting. They should enhance the training experience rather than disrupt the athlete's focus. Athletes come from diverse training backgrounds and have varied familiarity levels with VR. The interaction interface should be customizable to cater to beginners and advanced users alike, ensuring a seamless transition into VR-enhanced training [63].

5.2. Future trends

The dynamic landscape of motion capture in VR for sports training is on the cusp of revolutionary advancements. As we look ahead, several trends emerge, promising to reshape and refine the domain further [78,91].

From a technical standpoint, the integration of Artificial Intelligence (AI) and deep learning promises to redefine the boundaries of motion capture in VR [53,55,107,119]. These technologies will not only enhance data analysis but will also provide predictive insights, enabling athletes to make preemptive adjustments. Additionally, as hardware components become more sophisticated, we can anticipate a shift towards a more seamless and integrated experience. Athletes will benefit from miniaturized sensors [54], longer battery life [99], and lighter VR headsets. Furthermore, the convergence of Augmented Reality (AR) with VR, culminating in Mixed Reality (MR), will introduce multi-dimensional training experiences, blending real-time feedback with immersive environments [96].

In terms of application, the future beckons a shift towards more adaptive training regimes [116]. These programs, driven by real-time data and analytics, will constantly evolve, adjusting to an athlete's performance and ensuring optimal skill development. As the technology becomes more accessible and versatile, its reach will extend to specialized sports disciplines, including ice skating and swimming, ensuring a broader spectrum of athletes benefit from advanced training tools [75].

However, with these advancements come societal implications. As motion capture in VR becomes more prevalent, we can expect its adoption to spread beyond elite athletes, reaching local gyms, schools, and rehabilitation centers. This democratization of advanced training tools will inevitably raise concerns about data privacy and security [11]. Safeguarding athletes' biomechanical data will be paramount. Moreover, as the lines between motion capture data and health metrics blur, there will be a synergistic relationship between sports training, medicine, and overall health monitoring [82]. This integration will play a pivotal role in injury prevention, recovery optimization, and holistic athlete well-being.

6. Conclusion

In the rapidly evolving world of sports training, the intersection of motion capture and VR stands out as a beacon of transformative potential. This systematic review embarked on a journey to explore this convergence, aiming to provide clarity on its implications and future trajectory.

Our study was rooted in the backdrop of a rising demand for precision and personalization in sports training. The primary objective was to elucidate the transformative potential of integrating motion capture with VR, emphasizing its capacity to redefine training methodologies. Through a rigorous examination of existing literature, we unearthed the multifaceted applications of this fusion, from enhancing physical conditioning to facilitating accelerated rehabilitation. Our findings underscored the undeniable benefits of integrating motion capture with VR, most notably, its capacity to offer real-time feedback, immersive training environments, and tailored training regimes. However, this potential doesn't come without challenges. From hardware limitations to data privacy concerns, the road to seamless integration is riddled with obstacles. But, as with any nascent technology, these challenges pave the way for innovation.

Looking ahead, the future of motion capture in VR sports training is brimming with promise. As AI and deep learning find their footing in this domain, and as hardware becomes more sophisticated, we can anticipate a revolution in sports training. Furthermore, the societal implications of this technology's wider adoption, coupled with its convergence with health metrics, signal a shift towards a more holistic approach to athlete well-being.

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Conflict of interest

The authors declare there is no conflict of interest.

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数字化转型赋能高职教育高质量发展路径研究

摘　要：目前,中国职业教育正呈现“六大趋势”:重心持续上移、职普融通、产教融合、数字化、国际化和“新双高”。数字化是职业教育发展的必然选择,也是实现职业教育高质量发展的必由之路。数字技术为职业教育的高质量发展提供了路径:以“数据...展开更多

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关 键 词：数字化转型 高职教育 高质量发展 赋能
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数字化转型赋能高职教育高质量发展路径研究*

□侯迪

摘要：目前，中国职业教育正呈现“六大趋势”：重心持续上移、职普融通、产教融合、数字化、国际化和“新双高”。数字化是职业教育发展的必然选择，也是实现职业教育高质量发展的必由之路。数字技术为职业教育的高质量发展提供了路径：以“数据”和“技术”为工具支撑，政府、学校、企业多主体协同，在思想层面确立“以人为本，技术辅助”的价值导向，在管理体系方面健全“人技互通，数字引领”的运行机制，在技术创新层面构建“广泛互联，适配性强”的数字资源服务平台。

关键词：数字化转型；高职教育；高质量发展；赋能

“大智移云物区”等数字技术的革新与发展，深刻促进了职业教育的数字化转型。作为“数字中国战略”的一部分，推进教育数字化是贯彻落实科教兴国战略、人才强国战略的重要先手棋，同时也是新时代赋予职业院校的历史使命，更是职业教育主动贯彻国家战略，服务经济社会数字化转型的必然选择。2020 年 5 月，国家发展改革委发布“数字化转型伙伴行动”倡议，标志着我国数字化转型全面进入新阶段[1]。2022 年 3 月，国家智慧教育平台正式上线，标志着教育数字化发展正式启航。

然而，高职教育高质量发展的时代内涵是什么？教育数字化转型赋能高职教育高质量发展的作用机制是什么？这些都亟须解决。唯有系统厘清问题脉络、深研发展机制，方能稳步推动教育数字化变革进程，最终达成高职教育高水平发展的目标。

一、高职教育高质量发展的时代内涵

现阶段，“高质量发展”理念已深度融入职业教育改革进程：2019 年国务院颁布的《国家职业教育改革实施方案》明确提出“推动高等职业教育高质量发展”[2]；2021 年 10 月中共中央办公厅、国务院办公厅联合印发《关于推进现代职业教育高质量发展的指导意见》，进一步深化高质量发展导向；2024 年 5 月，习近平总书记在中共中央政治局第五次集体学习时再次强调，教育数字化是开辟教育发展新赛道和塑造教育发展新优势的重要突破口。在新时代背景下，将“高质量发展”理念引入高职教育领域，既契合时代变革需求，更赋予高职教育现代化转型新的内涵与使命。

党的十九大报告提出的高质量发展理念，着重从时代特征角度阐释我国经济已实现历史性跨越——由规模速度型增长转向质量效益型提升，凸显出鲜明的时代演进特征。立足新阶段，我国经济社会运行的基础条件、内外环境以及社会主要矛盾均发生深刻变化。为精准把握职业教育改革发展的时代坐标，为科学确立发展目标、优化发展路径、明确建设重点提供根本遵循，高等职业教育领域迫切需要将高质量发展确立为核心发展战略。

将新发展理念运用到高职教育高质量发展的进程中，既是对国内外形势研判的结果，也是其必然选择。

高职教育实现高质量转型必须坚持“以人民为中心”的根本立场，以满足人民群众对高水平职业教育的需求为发展目标，真正实现“发展为了人民、发展依靠人民、发展成果由人民共享”的价值追求。

二、教育数字化转型赋能高职教育高质量发展的作用机制

（一）重构教育供给机制，以“强基”赋能体系构建

由于地理位置、区域经济等条件的限制，我国高职教育呈现出“孤岛化”特征，产、学、研、用环节割裂严重，无法满足新时代背景下高职教育的发展需求。而数字化转型为高职教育摆脱孤岛困境提供了有力支持：高职院校既可以通过构建数字化平台实现各个环节的融合，实现业务流、数据流与资源流的深度融合，又能够重构高职教育从“普通教育附属”转向“独立类型教育”的新发展形态，为构建纵向贯通、横向融通的现代职教体系提供技术支撑。

（二）优化教育服务流程，以“提效”赋能办学升级

目前，我国高职教育在管理环节普遍存在以下难题：信息化程度低，

课程安排、学分认定以及实训室调配等环节大量依靠人工，导致资源利用率低、响应迟缓现象的发生。而 RPA 流程自动化、AI 智能决策等数字化技术的应用，能够帮助高职院校实现教务管理、资源配置、质量监控等环节的智能化升级，推动高职教育服务流程从“经验驱动”向“数据驱动”转型[3]。以郑州智能科技职业学院为例，该校引入智能排课系统后，排课时间从平均 3 周压缩至 2 天，教室利用率提升了 37%。数字化管理的深层逻辑是流程优化，即通过数字化技术的应用释放教学资源，提高资源的利用率，助力学校形成“效率提升—资源再配置—办学质量跃升”的良性循环。

（三）革新教育治理模式，以“精治”赋能制度创新

数字化转型推动教育治理模式的革新主要体现在以下两个方面：一是管理方式的革新，即推动高职院校的治理方式从“经验决策”向“数据驱动”转变。以黄河科技学院为例，该校按专业类成立 24 个课题组深入产业调研，将调研结果“数据化”，形成对应 150 个专业的职位标签 2845 个，专业技能标签 9252 个，建设“产业—行业—企业分类标准、产业链人才需求标准、专业人才质量标准”三大标准数据库，改变了过去依靠经验进行人才培养的模式[4]。二是治理制度的革新，通过“数据赋能—制度松绑—多元共治”的路径，为高职教育治理现代化提供新方案。如河南省率先出台《河南省职业教育条例（草案）》，鼓励企业以技术、设备等数字资产入股办学。再如河南机电职业学院与富士康共建的工业富联智能科技职业学院，学校负责教学管理，学生毕业后直接进入企业技术岗位，实现“招生即招工、毕业即就业”的闭环。

（四）重塑技能培养路径，以“铸匠”赋能人才提质

数字技术与教育全要素的深度融合，能够构建以个性化学习为核心的数字教育生态，解决传统高职教育“重理论轻实践”“教学与生产脱节”等痛点。数字教育生态的主阵地在数字课堂：教师的数字教学、学生的数字学习、课堂的数字管理。数字化教学平台的使用能够帮助教师精准策划、匹配教学方案，发放教学任务，并追踪学生的学习成果，及时优化教学策略，为每一位学生定制数字化的学习图谱，充分激发每一位学生的学习潜能。学生可根据自身情况自主选择个性化的学习路径，通过数字化学习图谱选择更贴合自身情况的教学资源[5]。数字化管理通过数字化流程、数字化决策提高了教育管理的科学性、规范性、准确性和高效性。

三、教育数字化转型赋能高职教育高质量发展的路径探索

在高等职业教育数字化转型的既有实践基础上，结合国内外先进经验，未来高质量发展路径需以“数据”与“技术”为双轮驱动，构建政府、学校、企业多主体协同的生态体系。

（一）思想层面：确立“以人为本，技术辅助”的价值导向

教育数字化转型不是数字技术的简单叠加，而是通过数字技术重构教育生态，使高职教育成为培育新质生产力人才的主阵地。教育数字化转型本质上是教育主体的数字化转型，是教师和学生的数字化转型。高职教育的高质量发展必须以教师和学生为主体，将数字素养培育贯穿人才培养的全过程，构建与现代产业体系相适配的人才供给新生态，同时需要重点聚焦在以下三个方面：

一是聚焦教师数字能力的提升。高职院校整合人工智能、大数据等前沿技术，构建数智化的教师发展平台，建立符合教师发展的分层分类培训体系[6]。数智化的教师发展平台能够实现学情驱动的协同教研、跨域资源共享，提高教师在混合式教学、个性化辅导等场景中的数字应用能力，培育具备人机协同意识的新时代职教师资队伍。

二是聚焦学生数字素养的培育。一方面要深化通识教育中的技术认知，开发模块化数字技能课程，将数据思维、智能工具应用等要素融入专业教学；另一方面，要通过虚拟仿真、项目实践等创新场景，引导学生运用数字技术解决产业实际问题，形成“技术认知—技能训练—创新应用”的递进式培养路径。

三是聚焦教育评价体系的重构。高职教育的高质量发展亟须建立覆盖师生双主体的数字素养评估框架，该框架应包含动态监测信息获取、分析应用、创新实践等核心能力指标，能完成过程性数据采集与智能分析，形成个性化发展诊断报告，为优化教学策略、完善培训内容提供科学依据，构建“测评—反馈—改进”的闭环机制[7]。

（二）管理体系：健全“人技互通，数字引领”的运行机制

高职教育高质量发展必须以数据要素为战略支撑，构建数据驱动的现代化治理体系，通过信息资源深度开发利用推动高职教育发展革新。这种数据驱动的转型不是技术堆砌，而是

通过信息资源重构教育生态，使高职教育成为培育数字工匠的主阵地，在服务产业数字化进程中实现自身发展质量的提升。这一转型需聚焦三大核心路径：

第一，数据赋能的基础是构建智能采集体系。政校行企可以联合牵头研发符合高职院校特征的数据采集工具，建立全流程监测系统，实现教学行为、管理过程等动态数据的精准抓取。在此过程中要同步构建隐私保护机制，确保数据采集与应用合法合规，形成人机协同的良性互动模式。

第二，资源整合的关键是打造数据中台。鼓励高职院校和行业、企业通过制定统一的数据协议，打破数据壁垒，构建教育数据库，实现教务管理、学生发展、就业服务等全域数据贯通。还可以借助业务流再造技术，将离散的数据转化为发展势能，支撑招生培养联动、产教融合对接等关键环节的智能决策。

第三，价值实现的根本是培育循证决策能力。基于大数据构建教育发展模型，对教学实施、学习成效、治理效能进行多维度诊断。运用AI算法生成个性化诊断报告，为教师提供精准教学建议，为学生定制学习路径，为管理者提供科学决策依据，推动治理模式从经验驱动向数据驱动的根本转变。

（三）技术创新：构建“广泛互联、适配性强”的数字资源服务平台

高职教育高质量发展必须以教育新基建为战略支点，构建智能时代的育人新生态。这种新基建驱动的发展不是硬件堆砌，而是通过数字技术重构教育要素，使高职教育成为培育数字工匠的主阵地，在服务产业数字化转型中实现自身发展质量的跨越式提升：

夯实智能基础设施底座是物理支撑。高职院校高质量发展的基础就是数字教学场所的构建。该场所不仅要集成人工智能、虚拟仿真等技术，为学生打造“线上+线下”融合的沉浸式学习空间，还需要同步推进5G网络、数据中心云平台建设，构建全时域、零距离的智慧校园环境，支撑“处处可学、时时能学”的新型教学模式。

构建资源聚合平台是内容保障。第一，国家智慧教育平台等枢纽能够帮助高职院校整合优质数字资源，将离散的教育案例转化为系统的资源库。第二，交互式数字教材、智能学情分析系统等新型工具的开发使用，让欠发达地区师生通过专递课堂、同步课堂等形式实现了优质教学资源的共享，破解了区域资源不均衡的难题。

打造精准供给体系是价值实现关键。数字资源服务平台的构建为制定资源准入标准与质量评估体系，确保供给内容的权威性与时效性提供了方向。高职院校可以利用该平台，运用大数据分析学习者行为特征，构建个性化资源推送模型，满足不同专业、不同层次学生的差异化需求，形成“需求感知—精准匹配—动态优化”的供给闭环。

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课题项目：本文系河南省哲学社会科学教育强省研究项目“教育数字化转型赋能河南省高职教育高质量发展路径研究”研究成果（项目编号：2025JYQS0882，主持人：侯迪）；河南省民办教育研究会项目“教育数字化赋能河南省民办高职教育转型升级与质量提升的路径探索”研究成果（项目编号：YMY20251470，主持人：侯迪）。

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证 书

论文作者：李小慧、冯俊杰、范东方

论文题目：数字技术视域下竞技武术运动员体能训练的实践探索与优化路径

该论文被第十一届中国体能论坛录取为墙报交流，并参加了学术交流。

中国体育科学学会体能训练分会

中国体育科学学会代章

2025年10月19日

数字技术视域下竞技武术运动员体能训练的实践探索与优化路径

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关键词：数字技术；竞技武术运动员；体能训练

研究目的：随着数字科技的深度融入社会生活各领域，其发展动能日益凸显。2021 年 10 月，习近平总书记在主持十九届中央政治局第三十四次集体学习时强调："当今时代，数字技术、数字经济是世界科技革命和产业变革的先机，是新一轮国际竞争重点领域，我们一定要抓住先机、抢占未来发展制高点。"2024 年 11 月，习近平总书记在向 2024 年世界互联网大会乌镇峰会开幕视频致贺中提到，我们应当把握数字化、网络化、智能化发展大势 携手迈进更加美好的"数字未来"。习近平总书记的讲话为我们探索数字技术在竞技武术运动员体能训练中的应用指明了方向。数字技术视域下竞技武术运动员体能训练旨在探索数字技术，如可穿戴设备、动作捕捉、大数据分析、VR/AR 等数字技术在竞技武术运动员体能训练中的应用，分析其实践效果与存在困境，进而提出可持续发展的优化路径，以解决竞技武术运动员传统体能训练中出现的问题，推动武术体能训练的科学化与精准化转型，进而实现竞技武术运动员技术水平的高质量提升。

研究方法：以访谈法和实验法等研究方法选取某武校专业队 20 名套路运动员为实验对象，进行为期 12 周的实验干预，测出干预前后专项体能指标以及对武术教练员和运动员进行半结构化访谈，聚焦数字工具应用体验、接受度、主要障碍。

研究结果：实验结果显示：1）训练监控更为精细化，在实验中能够显示出相较于以往传统训练评估中教练员容易忽略的问题，如在腾空性动作旋风脚以及侧空翻转体过程中核心肌群最大化激活的先后时间以及落地缓冲阶段肌群的发力不均。2）负荷调控更加科学化，在训练过程中实时的生理数据及动作完成质量评定，动态调整训练强度与间歇。实验组的疲劳性损伤发生率较对照组有明显下降，相同周期内最大力量与无氧功率提升幅度显著更高。3）应用挑战效果显现，教练员与运动员认为使用问题主要表现为，穿戴使用复杂、多种数据分析复杂、传统经验与数据解读存在冲突、运动员存在初期设备适应性与"数据焦虑"等问题。

研究结论与建议：数字技术在武术体能训练的运用为高水平运动员的训练带来革命性提升，对纠正技术细节错误效果显著，实现了教练员从经验驱动向"数据驱动+精准反馈"的范式转变，在动作诊断、负荷量化、损伤预防、技术优化方面效能显著。然而，人技协同能力不足、数据整合壁垒、成本制约仍是阻碍其深度应用的瓶颈。应研发高性价比可穿戴传感设备，以便于运动员的穿戴方便，促进基层普及；开发武术专项体能训练整合系统，促进多源数据的整合，并提供可视化自动化分析报告，降低教练员和运动员的使用门槛；构建不同武术项目（长

拳、太极拳、南拳等）运动员体能特征模型与疲劳预测模型，为个体化训练处方提供基准；开展教练员与运动员的“数字素养”专项培训，培养其数据解读与决策能力；设计运动员数据反馈心理适应方案，避免过度依赖。

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文章目录

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我国民族传统体育特色学校改革的逻辑审视——基于河南省登封市武术学校改革的分析

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摘要： 民族传统体育特色学校作为我国体育事业发展的重要途径，对实现体育强国、健康中国起着重要的作用。文章运用文献资料法、实地调研法、逻辑分析法等研究方法，对河南省登封市武术学校改革前的不足、问题产生的根源、改革的深层动因、如何改革、改革结果展望以及改革的逻辑进行解析。研究认为：河南省登封市武术学校改革是适应新时代社会发展以及武术学校自身生存的调试，改革为河南省登封市武术学校的发展注入新的活力，为民族传统体育特色学校的发展提供指导与借鉴。研究意义：通过对河南省登封市武术学校改革的逻辑梳理，为我国武术学校教育的发展、传统武术的传承与发展提供了理论参考，从而更好地推动我国民族传统体育特色学校的可持续发展。

关键词： 民族传统体育；武术学校；改革；武术教育；

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我国民族传统体育特色学校改革的逻辑审视
——基于河南省登封市武术学校改革的分析

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摘　要：民族传统体育特色学校作为我国体育事业发展的重要途径，对实现体育强国、健康中国起着重要的作用。文章运用文献资料法、实地调研法、逻辑分析法等研究方法，对河南省登封市武术学校改革前的不足、问题产生的根源、改革的深层动因、如何改革、改革结果展望以及改革的逻辑进行解析。研究认为：河南省登封市武术学校改革是适应新时代社会发展以及武术学校自身生存的调试，改革为河南省登封市武术学校的发展注入新的活力，为民族传统体育特色学校的发展提供指导与借鉴。研究意义：通过对河南省登封市武术学校改革的逻辑梳理，为我国武术学校教育的发展、传统武术的传承与发展提供了理论参考，从而更好地推动我国民族传统体育特色学校的可持续发展。

关键词：民族传统体育；武术学校；改革；武术教育
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党的十八大以来，习近平总书记高度重视教育事业，对教育工作作出了一系列重要部署。高举中国特色社会主义伟大旗帜 为全面建设社会主义现代化国家而团结奋斗——在中国共产党第二十次全国代表大会上的报告中提出："我们要坚持教育优先发展、科技自立自强、人才引领驱动，加快建设教育强国、科技强国、人才强国，坚持为党育人、为国育才，全面提高人才自主培养质量，着力造就拔尖型人才，聚天下英才而用之。"[1] 习近平主持中央政治局第五次集体学习并发表重要讲话，"我们要建设的教育强国，是中国特色社会主义教育强国，必须以坚持党对教育事业的全面领导为根本保证，以立德树人为根本任务，最终是办好人民满意的教育。"[2] 民族传统体育特色学校作为我国教育体系的组成部分，对我国教育事业的发展有着重要的价值与意义，受到越来越多人的认可与肯定。但是在当前民族传统体育特色学校发展的进程中依然面临着种种困难，如，管理技术不到位[3]、文化教育短缺[4]、教学方式不够科学，教师队伍学历普遍偏低[5] 等严重制约着学校的良性发展。面对当前困境，怎样更好地深化民族传统体育特色学校教育改革，怎样更好地实现民族传统体育特色学校的可持续发展，怎样更好地实现办好人民满意的教育成为当前民族传统体育特色学校教育亟须解决的问题。登封市武术学校作为我国民族传统体育特色学校的发源地，集聚了数十万人的学生，自 2019 年登封武术学校改革以来，登封地区的武术学校获得更为良性的发展。由此，本研究以河南省登封市武术学校改革为例，探究河南省登封市武术学校改革的发展路径，对推动民族传统体育特色学校发展具有现实意义。

1　现实与困境：改革前的不足

2019 年，河南省登封市某武术学校由于登上了网络热搜，引起了轩然大波，使得民族传统体育特色学校改革以及民族传统体育的发展成为人们关注的焦点。"放眼登封，可谓'五步一馆、十步一校'，成为世界上最大的'武林部落'。"[6] 从几十名学生小规模的学校到数万名学生的集团化武校，习武人数达到数十万之众。"在 101 所武校中，经审批具备办学资质的有 28 所，习武场所有 60 所，未经批准的有 13 所。除了 28 家具备办学资质的武校外，其他练武场所均为借资质办理学籍"[7]，其中部分学校在管理与教育上存在对学生体罚、教练员管理松懈、学校安全隐患等问题，而且从该地区行政管理部门所呈现的材料中显示，

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当地个别武术学校在管理上存在着管理简单粗放、教学质量偏低、教学事故时有发生的情况。2019年，通过对登封市武校暗访后总结出以下几点：教练打学生屡见不鲜；武校教练公开索贿；民房挂块牌子变武校；习武场所许可证花钱就能办；武校文化课教学质量偏低等现象。在实际考查中发现，很多武术学校中存在着好勇斗狠、恃强凌弱的不良现象，教练在学习以及日常生活中体罚学生尤为常见，种种乱象严重阻碍了武术学校的良性发展。

2 共生与冲突：问题产生的表因

首先，河南省登封市武术学校开创之初大都是私人武馆，以传统社会中家族式的管理方式以及师徒制的教育方式开展武术教学。改革开放以来随着第九届全国人民代表大会常务委员会第三十一次会议通过《中华人民共和国民办教育促进法》的实施以及八十年代的《少林寺》电影引起的“功夫热”使河南省登封市武术学校走上了发展的快车道。为了适应武术学校自身发展以及社会需求，一些武校开始调整发展方向和发展规模，以少林塔沟教育集团、少林鹅坡武术学校、少林小龙武校等为首的武术学校走上了集团化发展道路，但是在发展过程中由于教育企业发展规模化的急速扩张，难免会造成在某些管理工作方面的缺失；其次，武术教育作为当地发展的支柱性产业，对河南省登封市经济发展起着重要的推动作用，在追求经济高速发展的社会背景下，当地有关部门对武术学校的监管相对松懈；再次，武校的生源来自全国导致学生学习武术的情况不一；最后，河南省登封地区大大小小的武校上百所，规模大小不一、层次不同，“各种小作坊式的武校屡见不鲜，从各个村庄延伸出的羊肠小道往里探，由民房改建的武校随处可见。”[8] 许多没有资质、管理滞后的武术学校、武馆、家庭式武术作坊，降低了登封市整体武术学校管理的水平，特别是一些隐藏在村庄民房中的武术学校，为登封市总体的武术产业发展带来了不利影响。

3 目标与雄心：改革背后的动因溯源

3.1 宏观层面分析

随着社会的发展，经济水平和文化水平都得到了大幅度提高，社会发展给人们的物质基础带来富足生活的同时也在改变着传统的价值观念。决胜全面建成小康社会 夺取新时代中国特色社会主义伟大胜利——在中国共产党第十九次全国代表大会上的报告中强调：“加强社会治理制度建设，完善党委领导、政府负责、社会协同、公共参与、法治保障的社会治理体制，提高社会治理社会化、法治化、智能化、专业化水平。”[9] 我国总体的社会格局发生了根本性的改变，由此，武术教育必须进行改革，方能适应社会发展的需求。从根本上来看，一是我国人口增长速度放缓导致社会整体的人口红利缺失，未成年适龄学生逐年减少；二是武术学校的生源关系着武术学校的存续；三是随着我国对职业教育的重视与提高，职业教育已经呈现出强劲的发展势头并且成为促进我国社会繁荣、科技进步、经济发展的重要基石。职业教育受到高度重视使适龄学生有了更多的发展道路；四是依法治国的治理理念高度提升，更多的人有意识保护自己的合法权益；五是西方竞技体育随着全球化浪潮对民族传统体育项目产生冲击，人们对运动项目有了多元化的选择，挤压了学校武术的发展空间。由此，从宏观层面可以看出武术学校的发展是随着社会的发展演进而不断变化发展，是在中国整个的宏阔社会背景下为了发展而不得不进行的自我更新与调适。

3.2 微观层面分析

武校作为登封市武术产业的重要部分，庞大的学生数量对登封市的经济发展起着一定的作用，如，提供就业岗位，促进本地区经济的发展。在2020年全国武术之乡年度评审工作会议中提到：登封市现有武术产业总规模达50多亿元，实现增加值30多亿元，提供2万多个就业岗位。登封市人民政府印发《登封市国民经济和社会发展第十四个五年规划和二〇三五年远景目标纲要》，未来的少林功夫发展将向着健身休闲、武术竞技、武术传媒、武术商贸等行业发展；培育武术旅游、研学旅行、武术养生、武术演艺、器械制造等“武术+”产业，并带动相关产业，基本建成结构合理、供给丰富、消费活跃、富有特色的武术产业体系，要把武校打造成“朝阳产业”，要创建“世界功夫之都”。

面对我国社会结构的转变以及上述问题，“如果放任登封市武校经济继续走粗放模式、发展中的乱象任其野蛮生长，那么‘朝阳产业’也将会变为‘夕阳产业’”[7]，无论是武术学校的经济抑或整个登封市武术产业都将会受到严重影响，对整个武术行业都会带来负面影响。对于河南省登封市来讲，本质上都是法制经济，都应该建立在政府以及社会的监管与监督之下，为实现短期的利益对武校乱象姑息纵容，只会让登封市的武术产业偏离正确航道，从而影响其长久发展，为登封地区的经济发展和武术文化的发展带来不利影响。

4 重塑与再构：改革路径的抉择指向

任何改革的和顺利实施，都离不开完善的制度保障。[10]2019年4月29日，登封市对武术学校进行了有针对性地专项治理动员大会，派遣11个专家组依法依规对全市武术学校“提升一批、规范一批、整合一批、取缔一批”，以全面提升武术学校管理水平，推动武术产业高质量发展，为加快建设世界历史文化名城、少林功夫国际旅游目的地提供有力支撑，[11] 由此，登封市针对武术学校出台了一系列政策，开始了紧锣密鼓的改革。

4.1 加强制度建设，提升政府监管力度

对武术学校进行专项治理，不断提升、规范武术学校各项制度建设，提高各个职能部门的监管力度。

明确出台从事武术学校教练人员的行业标准，从严从细制定从业规则，健全准入制度；建立武术学校教练员“黑名单”、武术学校“黑白名单”制度，对经常上榜“黑名单”人员或武术学校从严处罚；加强教练员任职管理和加强武术学校安全防范管理，特别是针对校园暴力与校园欺凌事件，加强监管力度，实现武术学校监控全覆盖并与公安监控系统对接联网，特别是针对青少年儿童实行“一寝一探头”，制定主要人员安全责任制。制定规范的招生监管制度，取缔没有招生资质的武术学校以及“民间大师”的习武场所，清查夸大虚假宣传招生，欺骗、强拉学生习武的违法行为，严格执行地方政府制定的武术学校招生条例。

4.2 加强思想管理

思想管理是发展的必要保障。武术学校要加强在各项工作上的思想意识，不断增强管理意识。要制定长期的思想管理学习规划，对武术学校校长、中层管理干部定期组织培训，不断提高管理能力和管理素养；针对国家实施的政策法规，开展政府思想教育进校园活动，并定期举办思想教育活动演讲，对工作一线的教练员、教师、在校工作人员进行思想教育，加强一线教职工的政治素养；向学校派驻思想指导员，对学生进行思想教育，提升学生的道德素养。

4.3 完善基础，改善软硬件办学条件

加强武术学校的基础设施建设，改善办学条件。针对武术学校的教学特色，加强武术学校训练场馆的建设，制定武术学校室内外武术训练场馆占地面积标准，严格规划训练场地。加强教学楼、住宿楼、餐厅的拓建工程；实现“互联网+明厨亮灶”工程建设全覆盖，引进专业厨师队伍；配备电脑网络计算机，扩充图书馆藏书，设计校园文化长廊，增加体育娱乐器材，丰富教室文化氛围、校园娱乐设施等基础设施的扩建与改建。

4.4 加强安全管理，提升师生安全意识

建立警务室，实行“一校一警”或“一校多警”的监管值守制度，实行监控全覆盖，提高学校的安全管理，保障师生人身安全；针对武术学校暴力事件，加强学校的安全防控和法治思想教育，要从思想上提高认识，针对性地开展法治安全专项培训，增强师生思想安全意识；加强对武术学校管理及从业人员安全理论和安全技能的培训，强化安全措施，落实安全责任。

5 守正与拓展：改革结果的现实展望

登封市武术学校的教育改革，从社会层面、政府层面、武术学校自身、学生主体以及民族传统武术本体等各个方面都得到了极大发展。从社会层面来说，武术学校改革进一步规范了社会问题，减少了由于武术教育问题所带来的矛盾；从政府层面来看，对登封市武校的改革进一步提升了登封市武术行业在社会的声誉，地位得到了进一步的稳固，为登封市武术经济的可持续发展注入新的活力；从武术学校自身来看，科学化、规范化的现代管理方式为登封市武术学校的长久发展打下了良好的基础；从学生主体来看，武术学校的改革为学生塑造了一个安全稳定的学习环境，同时教学的规范、教师专业能力的提高也为学生的专业知识、道德素养的习得提供了强有力的保障；从传统武术本体来看，登封市武术学校作为武术教育基地，武术教育的改革能够为民族传统武术的传承与发展提供源源不断的动力。

6 我国民族传统体育特色学校改革的逻辑解析

我国民族传统体育特色学校的改革进一步促进了民族传统体育行业向规范化、专业化、现代化方向迈进。当前登封市武术学校粗放的管理模式、简单的教学方式已经无法适应新时代社会的发展需求，随着社会整体自我意识的觉醒，学生个人对于自我和自尊的保护越来越高，而这种认识的提高意味着如果我们继续按照传统的教学模式就会产生更多的矛盾，事实上，登封市武术学校的改革在实现集约化后，在某种意义上削减了学校的数量，使得武术学校整体的运行成本得以控制。尽管学生数量减少，实际上武术学校的发展得到了提升，这种改革更有利于管理的现代化、制度化、精细化，为武术学校的可持续发展提供根本保障。在此，我们要正视我国民族传统体育特色学校在发展进程中存在的问题，遵循事物发展的普遍规律。我国民族传统体育特色学校改革是民族传统体育发展的重要举措，是实现学校现代化、科学化、可持续化发展的重要途径，科学化、合理化的民族传统体育特色学校改革具有较强的现实意义。

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基于深度学习的图像识别算法优化策略探究

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摘要： 为有效降低森林火灾对生态环境和人类安全的威胁,文章开发了一种基于深度学习的火灾早期识别技术.通过深入探究图像识别算法的优化策略,构建了一个采用改良SSD算法的图像识别系统.该系统利用TensorFlow框架实现,并通过Imgaug图像增强库对训练数据进行了丰富处理,构建了一个包含多种火灾场景的数据集.在该数据集上进行模型训练和测试,评估模型性能的指标包括损失函数曲线和精确率-召回率曲线.实验结果表明,随着训练次数的增加,模型损失将逐步减少,而识别精度将显著提升.经公开FLAME数据集验证,模型的平均精度达到97.40%,漏检率降至0.03,平均检测时间仅为0.07 s,展现了良好的...

关键词： 图像识别; 深度学习; SSD目标检测算法

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❖学术探讨

❖行业动态

基于深度学习的图像识别算法优化策略探究

郎波霏,张方超

(郑州智能科技职业学院,郑州 450099)

摘　要：为有效降低森林火灾对生态环境和人类安全的威胁,文章开发了一种基于深度学习的火灾早期识别技术。通过深入探究图像识别算法的优化策略,构建了一个采用改良SSD算法的图像识别系统。该系统利用TensorFlow框架实现,并通过Imgaug图像增强库对训练数据进行了丰富处理,构建了一个包含多种火灾场景的数据集。在该数据集上进行模型训练和测试,评估模型性能的指标包括损失函数曲线和精确率—召回率曲线。实验结果表明,随着训练次数的增加,模型损失将逐步减少,而识别精度将显著提升。经公开FLAME数据集验证,模型的平均精度达到97.40%,漏检率降至0.03,平均检测时间仅为0.07 s,展现了良好的火灾识别能力。这一成果为森林火灾的早期识别和预警提供了有力的技术支持,对保护生态环境和人类安全具有重要意义。

关键词：图像识别;深度学习;SSD目标检测算法

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Exploration of optimization strategy for image recognition algorithm based on deep learning

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Abstract: To effectively reduce the threat of forest fires to the ecological environment and human safety, this article developed a deep learning based early fire recognition technology. Through in-depth exploration of optimization strategies for image recognition algorithms, an image recognition system using an improved SSD algorithm was constructed. The system is implemented using the TensorFlow framework and enriched the training data through the Imgaug image enhancement library, constructing a dataset containing multiple fire scenarios. Train and test the model on this dataset, and evaluate its performance using metrics such as loss function curve and accuracy recall curve. The experimental results indicate that as the number of training iterations increases, the model loss will gradually decrease, while the recognition accuracy will significantly improve. After verification with the publicly available FLAME dataset, the average accuracy of the model reached 97.40%, the missed detection rate decreased to 0.03, and the average detection time was only 0.07 seconds, demonstrating good fire recognition ability. This achievement provides strong technical support for early identification and early warning of forest fires, which is of great significance for protecting the ecological environment and human safety.

Key words: image recognition, deep learning, SSD object detection algorithm

1　引言

在森林火灾预防和控制领域,瞭望塔监测和烟雾探测器等传统方法逐渐暴露出反应迟缓和成本高等缺点。尽管卫星遥感技术能够覆盖广阔的区域,但在数据更新和细节捕捉方面存在一定的局限性,因此无法实现较为精准的小规模火灾检测。近期,无人机技术的兴起为精准快速的森林火灾检测提供了新的可能。但现有多数方法对火焰特征的识别仍依赖于人工,导致检测效率受到了限制[1]。随着深度学习技术的发展,Faster RCNN、YOLO和SSD等基于卷积神经网络的图像识别算法在火灾识别领域展现出良好的性能[2]。本研究聚焦于探索和优化SSD算法在无人机平台上的应用,旨在加快与提升对早期森林火灾微弱火点的识别速度和准确度,从而为森林火灾的及时预警与减损提供技术支持。

调整学习率和动量[4]。在完成所有迭代后，保存了包含TensorFlow计算图、断点信息和网络权重的模型状态。最终，将迭代结束时保存的模型文件(ckpt文件)作为最佳模型，用于后续的森林火灾检测和性能评估。

2.6 模型的性能评估与对比分析

模型表现评估一般分为初步观察和深入分析2个阶段。初步观察阶段通常采用新的图像测试模型，以检查其是否能准确识别目标区域并给出相应的置信度，从而评估模型对特定特征的识别能力。其中，该阶段通常借助特征图的可视化来直观展示模型对特征的捕获效果。深入分析阶段则关注模型训练过程中损失函数的变化轨迹，并计算模型的平均精度(mAP)。损失函数的降低通常意味着模型性能的提高，mAP这一评价指标可在不同阈值下综合考量精确度($Precision$)和召回率($Recall$)，从而反映模型在各类别上的平均表现，计算公式为：

$$\begin{cases} Precision = \dfrac{TP}{TP+FP} \\ Recall = \dfrac{TP}{TP+FN} \end{cases} \tag{4}$$

其中，TP是被正确识别为林火的样本数；FP是被错误标记为林火的样本数；FN是实际为林火但未被模型识别的样本数[5]。模型的性能评估不局限于单一指标，还包括对漏检率的考察，尤其是在森林火灾检测这类对准确性要求极高的应用场景中。

3 结果分析

3.1 森林火灾特征识别的视觉表征分析

在进行深度学习模型的视觉特征分析时，本文将VGG16架构作为基础的特征提取网络。该网络通过卷积层有效捕获了火灾图像中的关键视觉特征，包括颜色和纹理等。对不同卷积层输出的特征图进行集成和可视化处理，能够评估模型在各层级上对火灾特征的响应能力。通过分析输入图像经过的第1(64个滤波器)到第16个卷积层(512个滤波器)产生的特征图集，图1明确揭示了火焰的纹理和形状细节，说明模型在浅层网络中主要关注图像的基础特征(如边缘和纹理信息)。随着网络深度的增加，高级层次的特征图分辨率有所降低，反映出网络对图像的高层次、更抽象的语义特征有了更为深入的学习和理解，这些特征对于特定的目标(包括火焰)更为敏感。

3.2 模型的评估结果

在对林火图像数据进行检测时，采用的模型展现了较为理想的识别效果，单一火点场景下的置信度可达100%。在有多个火点且背景复杂的情况下，虽然置信度略有下降，但模型的边界框标注仍然准确。针对实际森林火灾中火点可能受到遮挡的情况，本文进行了相应测试。结果表明，当火焰部分受到一定程度的遮挡或面临烟雾干扰时，模型的置信度会有所降低，但仍能保持在80%以上，说明模型具有一定的泛化能力和适用性。

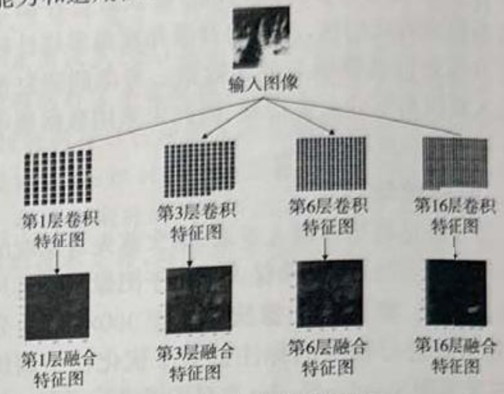

图1 森林火灾特征识别图

通过可视化处理，可以看出模型对火源点的识别与人眼识别的真实框位置在测试集上基本重合，较小的火源目标也能被准确识别。值得一提的是，模型能识别火灾后的剩余物，虽然在标定过程中未专门标注这部分内容，但模型在训练过程中学习了相关特征，在测试时将其成功检测到。这表明模型对森林火灾发生后的场景具有一定的判别能力，尽管可能存在误判的情况。

3.3 参数评估分析

本文对林火检测模型的参数进行了细致评估，在设置上借鉴了SSD模型在Pascal VOC 2007数据集上的训练方法。通过分析模型的交叉熵损失、位置损失及总体损失值随训练迭代次数的变化，可以观察到损失值呈现下降趋势，显示出模型的收敛情况。其中，交叉熵损失的减小反映了模型识别精度的提高，而位置损失的降低表示预测框与真实框之间的差异越来越小。通过进一步的分析，模型的损失值从训练初期的35.31逐渐降至7.10，表明模型在训练后达到了较高的识别精度。

本文对模型的识别精度进行了可视化处理，通过绘制精准度和召回率的P-R曲线，可以清楚地了解模型的性能。如图2(a)所示，P-R曲线所覆盖的面积占正方形总面积的比例是模型的平均精度(mAP)。经计算，本模型的mAP达到了97.40%，能够满足多数场景下对森林火灾初期的检测需求。同时，如图2(b)所示模型对疑似火灾特征的漏检率仅为0.03，说明对火焰特征具有较强的敏感性，能够有效识别火灾特征，为林火检测提供了有效的支持。

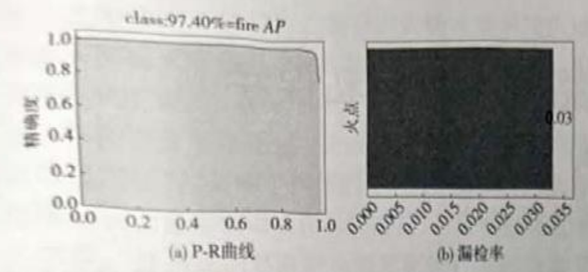

图2 林火检测模型的P-R曲线和漏检率

4 结束语

基于深度学习的多目标检测技术，本文成功开发了一种森林火灾图像识别模型。通过在优化SSD目标检测算法并结合TensorFlow框架后，对火灾图像中的火焰特征实现了高效识别。基于FLAME数据集的测试结果显示，所提模型的*mAP*达到了97.40%，漏检率仅为0.03，平均检测时间为0.07 s，表明该模型具有较高的识别精度和实时性。此外，模型对单一火点和多火点场景均表现出良好的识别效果，即使在火点受遮挡或面临烟雾干扰的情况下仍能保持较高的置信度。未来，可以进一步探索模型在更复杂环境下的适应性和泛化能力，并将模型应用于实际的森林火灾检测与预警系统中，从而为减少生态系统损害及人类损失提供技术支持。

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标上均优于常规的LSTM音乐生成网络，但与真实音乐相比仍存在差距。

5 结束语

为了让模型学会和弦进行对音符选择的约束，本文引入了强化学习的训练方法。利用和弦进行奖励和状态价值来构建Critic网络，进一步更新了Actor网络的生成策略。实验结果证明了本文方法的有效性。然而，本文生成的音乐与真实音乐之间仍存在差距，因此提高生成音乐的质量仍需进一步研究。

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人才强国战略下复合型创新人才培养的价值意蕴与路径选择*

王明瑞　李加州

摘　要：作为一项复杂的系统工程，培养复合型创新人才是建设人才强国的必经之路。文章采用文献研究法、案例分析法等方法深层次梳理了复合型创新人才培养的深刻内涵与重要价值，在此基础上进一步提出高校培养复合型创新人才应尽快转变培养理念、不断创新课程设计、深入变革培养模式和加快转变评价范式。

关键词：人才强国；复合型创新人才；新质生产力；人才培养；产科教融合

高校既是培育复合型创新人才的前沿阵地，也是创新成果研发的重要平台，更是整个国家知识创新体系的核心高地，为经济社会发展提供关键的人才支撑。在此背景下，广大高校能否准确把握实施人才强国战略对培养复合型创新人才的要求，探索出一条具有中国特色的创新人才培育路径，不仅仅是高校人才培养要回答的一道必答题，更是国家和社会发展必须研究的一项重要时代课题。[1]

一、人才强国战略下复合型创新人才培养的内涵与价值

（一）复合型创新人才的内涵本质

从人才能力向度看，人才可划分为创新型、技术型和管理型。创新型人才有着广博的知识结构，具备前沿的创新意识、思维和能力等。具体来看，创新型人才可分为应用型创新人才、研究型创新人才、创新创业人才等[2]。从人才知识结构角度看，人才可划分为复合型与单一型。简而言之，复合型人才是一专多能的人，是兼具“通”与“专”的整合型人才，具备复合性知识、综合性能力和创新性思维。其中复合性知识表现为个体精通多门学科理论和基础知识，且知识的交融性强；综合性能力是指个体实践操作技能比较强，能够灵活运用各类知识并开展创造性活动；创新性思维表现为个体能创新性地分析问题、解决问题。可见，复合型创新人才是指具有至少两门专业或学科的理论知识与实践能力，并在邻近专业之间可以实现知识、能力等深度渗透的人才。具体来看，其一，复合型创新人才的创新意识和能力更强。其二，复合型创新人才知识结构多元化，进一步打破学科固有壁垒，创新思维活跃。[3]其三，复合型创新人才的综合素质突出，能够持续深化知识融合、能力渗透和素质提升。

（二）复合型创新人才培养的价值意蕴

1.满足国家战略需求的必然选择。加快建设教育强国，必须全面提升人才培养质量，下大力气培养更多领域的多元化复合型创新人才。现阶段，围绕前沿科学技术的国际竞争日益激烈，复合型创新人才是推动科技发展的主力军，壮大战略科技力量必须储备一大批高层次创新人才。现代化建设离不开基础学科领域的大批学术型人才，也离不开卓越工程师等大国工匠。日益完善的人才布局是中国于激烈的国际竞争中抢占主动权的关键。复合型创新人才处在人才体系的顶端，是实现科技自立自强的核心。

2.支撑新质生产力发展的必经之路。复合型创新人才是新质生产力发展的关键动力。培养复合型

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* 本文系河南省高等教育教学教改研究与实践（重点）项目“双高背景下基于四链融合的数字工匠人才培养模式研究与实践”（编号：2024SJGLX0674），河南省高等教育教学改革研究与实践项目“数字中国视域下高职院校‘三教’改革发展路径研究”（编号：2021SJGIX821），2022 年郑州市教学名师培养项目“郑州市教育局办公室关于公布 2022 年度郑州教学名师第二层次培养对象名单的通知”（编号：郑教师函【2023】376 号）的研究成果。

创新人才是联系新质生产力发展与教育改革的纽带。在产业变革加速演进的背景下，培养复合型创新人才能够满足新质生产力对创新人才的需要。复合型创新人才能够更好地适应产业技术升级换代并灵活应用科技知识，促进新质生产力发展。复合型创新人才对新质生产力发展的支撑作用主要体现在促进前沿技术创新、催生战略性新兴产业、形成现代化产业体系与提升中国核心竞争力等方面。一方面，高校培养复合型创新人才将进一步深度融合教学与科研，发挥科教融合作用，凸显复合型创新人才对科技创新的独特优势，推动新质生产力发展。另一方面，随着新质生产力发展对复合型创新人才需求的增加，高校将持续提高复合型创新人才的岗位适应能力，进而不断促进新质生产力高质量发展。

3.建设高质量教育体系的迫切要求。教育提供的学习资源与机会，应该最大化地适应每一位学生的需求，建设高质量教育体系应该为学生成长成才铺平道路，力争为每一位学生提供满足其需要的教育服务，并及时回应不同学生的不同需求。教育应该为复合型创新人才提供相应的资源和机会，营造良好的学习环境。构建高质量教育体系是新时代教育发展的重要战略任务，培育复合型创新人才是构建高质量教育体系的迫切要求。中国高等教育急需回应人才强国建设与创新型国家建设对复合型创新人才的迫切要求，切实把培养复合型创新人才作为当前和未来高等教育发展的重点工作，加快形成国际人才竞争的强大优势，早日打造全球重要的创新人才中心。[4]

二、人才强国战略下复合型创新人才培养的路径选择

（一）培养理念转变：从知识传授到注重知识、能力、素质综合发展

随着社会对应用型人才的需求越来越大，不少高校的人才培养理念也在改变，追求更多元、更开放的培养理念，更重视开展跨越学科、院系以及地域的人才培养。如科教融合、产教协同等人才培养模式就是基于多元性、开放性理念做出的人才培养模式改革。可见，现代教育理念更看重知识向能力的转化，突出知识、能力素质的相互作用和全面发展。

所以，高校必须树立科教融合、专创融合等教育理念，结合知识生产的跨学科性和社会需求的多样性改革人才培养模式。[5] 一方面，高校要进一步深化对大学属性的认识，明确大学办学的根本目标，对学生实施综合性教育。另一方面，高校要充分尊重学生的个性化学习需要，在此基础上设计跨学科人才培养模式。

（二）课程设计创新：从单一学科课程到综合性、跨学科、国际性课程构建

1.设置跨学科课程，及时更新课程内容。知识生产的跨学科性要求高校培养复合型创新人才的课程设置要具有综合性，包括通识类创新课程、专创融合的跨学科课程，引导学生及时了解新质生产力发展的新特点。设计通识类创新课程要全面考量内在的知识逻辑、学科之间的衔接、社会发展需求、学生的多样化需求等要素。专创融合的跨学科课程要融入创新意识激发、创新精神培养等要素，突出课程内容的国际化和前沿性，追踪学科前沿问题，聚焦跨学科领域的研究动态。

2.加强实践教学，改革高校创新创业实践平台。高校既要增加实践教学频率，让每一位学生都能亲身参与实践学习，也要提升教学研究的实践性，调动学生进行教育研究的积极性。一方面，高校要聚焦产业发展的需要科学设计实践教学体系，构建产学研协同的人才培养模式，推动科技成果转化，打造集产业、人才、资金、创新于一体的人才培养体系。另一方面，高校要强化实验室、协同创新平台、智库等创新创业机构建设，加强科研基地、重点实验室等创新资源向复合型创新人才开放。

3.创新教学方法，推动信息化教学手段的应用。高校培养复合型创新人才，要充分利用信息化教学手段着力创新教学方法。利用人工智能等信息技术能够为课堂教学提供多样化资源，通过对知识点掌握的准确诊断、对学习方法的精准推荐促进课堂教学智慧化转型；也能够通过建立信息化服务体系完善课堂教学结构，形成立体化的智慧课堂。

（三）培养模式变革：从单一学院培养到产科教融合培养

1.产教研协作育人，加强多主体深度合作。首先，高校要重视科研成果教学转化。在梳理学科发展脉络的基础上，把科研成果引入课堂教学，重点向学生介绍新的科学研究方法与成果。其次，高校要把企业生产中遇到的实际问题作为科研项目渗透到课堂教学中。引导学生针对这些科研项目进行研究性学习、探究式学习、小组化学习。最后，高校应着力完善产教研协作育人体系，深化协同创新。既要衔接好创新领域、产业领域等外部资源，深化

横向协同，也要衔接好各学段人才培养，深化纵向贯通，遵循从本科到硕士再到博士的长周期贯通式培养模式。

2.社会实践育人，加强课程化、项目化、基地化建设。首先，高校可以把社会实践作为必修课程纳入教学计划，科学制定教学大纲及教学管理办法。其次，高校要依托实践项目锻炼学生的创新思维，深化学生对专业知识的把握和应用。最后，高校要充分发挥实践基地特有的辐射功能、汇聚功能，全面分析企业对人才的新需求，加强实践基地建设，将实践基地打造为创新能力培养的孵化器，最大限度地利用学校与社会主体在人才培养中的不同优势，重点强化学生领悟、掌握和灵活应用专业知识解决实际问题的能力。

3.培育机制育人，创新人才培养机制改革。首先，高校要进一步完善双学位培养和联合学位培养模式。在培养目标上，要帮助学生重点掌握多门学科理论、知识以及能力素养。在课程结构上，既要突出专业基础知识，也要强调不同专业知识体系的相互渗透。其次，高校要积极探索特色专业培养模式。依托本校优势专业学科的优质资源，满足学生个性化成才需要，实现对复合型创新人才的特色化培养。最后，高校可以积极探索书院制的培养模式。进一步打破学科与专业限制，营造文理相融、专业互补、促进学生个性化发展的全方位育人氛围。

（四）评价范式转向：从单一终结性评价转向多元评价范式并存

1.改变单一评价机制，实现综合、多元、科学的评价。首先，高校要构建以生为本的质量评价体系，建立校内校外联动的评价考核机制，动态关注学生学习的习惯、经验和效果，不断激发学生的创新动力。特别要完善动态性评价和形成性考核，可以借助大数据技术采集结构化信息和科学的测评结果，推动教育质量评价长效化。其次，根据创新价值、贡献、潜力等构建分层性评价体系，而不能只关注发表论文的数量，以科学的标准引导复合型创新人才潜心研究。最后，拓展评价主体和评价内容。组织教师、学生、企业、专家等作为评价主体，客观、全面地做好教育质量评价。针对评价内容，高校还要把学生的创新能力、问题解决能力等纳入评价内容。

2.建立多元评价体系，鼓励学生个性发展与创新实践。高校培养复合型创新人才，要遵循更全面、更科学、更有操作性的原则开展多元评价，关注学生的创新实践能力、方法等。更全面的原则要求评价体系必须涉及学生的知识理解、技能掌握、情感态度以及价值观等多个要素；更科学的原则要求评价方法、评价手段和评价标准要有科学依据；更有操作性要求评价工作的具体实施容易操作，适用于本科生培养、研究生培养等不同教育阶段以及不同学科领域。同时，高校要积极开展学生个性化发展评价，根据学生课程选修、参与兴趣小组等个性化发展动态开展评价，激励学生充分发挥自身特长。

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数智时代背景下高职院校智能智造专业群建设中教学质量诊断机制的优化路径

王明瑞

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摘要：在数智时代背景下，高职院校智能智造专业群的建设面临新的机遇与挑战，教学质量诊断机制作为保障专业群发展的重要环节，亟需优化与创新。本文通过分析现有诊断机制的现状与问题，结合数智时代的技术驱动与教学模式变革，提出了一系列优化路径，旨在构建智能化诊断平台、加强数据采集与共享、强化诊断结果的应用、推动个性化诊断与支持以及建立持续改进机制，为高职院校智能智造专业群的教学质量诊断提供系统化的改进方案，推动专业群建设的高质量发展。

关键词：数智时代；高职院校；智能智造；专业群建设；教学质量；诊断机制

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数智时代的到来，以大数据、人工智能、物联网为代表的新兴技术正在深刻改变教育领域的教学模式与管理方式。高职院校智能智造专业群作为培养智能制造领域高素质技术技能人才的重要载体，其教学质量直接影响人才培养的效果与专业群的发展水平。[1] 然而，传统的教学质量诊断机制在数据采集、分析工具、反馈应用等方面存在诸多局限，难以适应数智时代的需求。[2] 因此，优化教学质量诊断机制成为当前高职智能智造专业群建设中的一项紧迫任务。本文将探讨数智时代背景下高职智能智造专业群教学质量诊断机制的优化路径，期望为高职院校智能智造专业群的教学质量提升与可持续发展提供有力支撑。

一、高职院校智能智造专业群教学质量诊断机制概述

（一）诊断机制的定义与功能

教学质量诊断机制是通过系统化的方法对教学过程、教学效果及学生学习成果进行监测、分析与评价的过程，其核心功能包括实时监测教学动态、发现潜在问题，通过科学指标评估教学目标的达成情况，为教师、学生及管理者提供改进建议，促进教学质量的持续提升。

（二）现有诊断机制的主要内容

目前，高职院校智能智造专业群的教学质量诊断机制主要包括诊断指标体系、诊断工具与方法以及诊断流程，其中诊断指标体系涵盖课程设计、教学方法、学生学习效果、教师能力等多个维度，诊断工具与方法包括问卷调查、课堂观察、学生成绩分析、教学档案审查等，诊断流程则分为数据采集、数据分析、结果反馈与改进实施四个阶段。[3]

（三）存在的问题与挑战

现有诊断机制在实际应用中存在数据采集不全面、分析工具落后、反馈机制不完善以及教师与学生参与度不足等问题。传统方法难以覆盖教学全过程，缺乏智能

化手段，诊断结果反馈滞后，改进措施落实不到位，导致诊断效果受限。[4-5]

（四）数智时代对诊断机制的新要求

在数智时代背景下，教学质量诊断机制需要以数据驱动为核心，[6] 利用大数据技术实现教学数据的全面采集与深度分析，引入人工智能技术提升诊断的精准性与效率。通过物联网等技术实现教学过程的实时监控与动态调整，并关注学生个体差异，提供针对性的诊断与改进建议，以满足个性化教学的需求。

二、数智时代对教学质量诊断机制的影响

（一）数据驱动的全面采集与分析

数智时代的大数据技术为教学质量诊断机制提供了前所未有的数据支持。传统诊断机制往往依赖有限的样本数据，如问卷调查或课堂观察，难以全面反映教学全貌。而大数据技术能够实时采集海量数据，包括学生的学习行为数据、教师的教学表现数据以及课程的实施效果数据。这些数据的全面性与精准性为诊断机制奠定基础，使得教学质量分析更加客观、全面。此外，大数据技术还能够通过数据挖掘与分析，发现隐藏的教学规律与问题，为教学改进提供科学依据。

（二）智能化诊断与精准反馈

人工智能技术的应用显著提升了教学质量诊断的智能化水平。传统诊断方法依赖人工分析，效率低且容易受到主观因素影响。而人工智能技术，能够快速处理海量数据，识别复杂模式，并生成精准的诊断报告。通过分析学生的学习行为数据，AI 能够预测学生的学习困难点，并为教师提供个性化的教学建议。同时，AI 还能够通过智能问答系统，实时解答学生的疑问，提升学习效率。这种智能化诊断不仅提高了诊断的准确性与效率，还为教学改进提供了更具有针对性的反馈。

（三）实时监控与动态调整

物联网技术的普及使得教学过程的实时监控成为可能。通过智能设备与传感器的部署，教学活动中的关键数据（如课堂参与度、设备使用情况）可以被实时采集并传输到诊断系统中。这种实时监控能力使得教学质量诊断不再局限于事后分析，而是能够动态跟踪教学活动的实施情况，及时发现并解决问题。例如，当系统检测到某节课的学生参与度显著下降时，可以立即向教师发出预警，并建议调整教学方法。这种动态调整机制不仅提升了教学的灵活性，还显著提高了教学效果。

（四）教学模式变革的适应性需求

数智时代推动了教学模式的深刻变革，线上线下混合式教学、个性化学习等新模式逐渐普及。这些变革对教学质量诊断机制提出了更高的要求。[7] 传统诊断机制主要针对线下课堂教学设计，难以适应混合式教学与个性化学习的复杂需求。因此，诊断机制需要更加灵活、多样化的工具与方法。针对个性化学习，诊断机制需要能够识别学生的个体差异，并提供定制化的学习建议。这种适应性需求推动了诊断机制的创新与发展。

（五）数据驱动的决策与管理

数智时代强调数据驱动的决策与管理，教学质量诊断机制需要与学校的管理系统深度融合。传统诊断机制往往独立于学校的管理系统，诊断结果难以被有效应用于管理决策。在数智时代，诊断机制可以通过与学校管理系统的数据共享与协同，实现教学质量的实时监控与动态调整。这种数据驱动的管理模式不仅提升了学校的管理效率，还为教学质量的持续改进提供了有力支持。

三、高职院校智能智造专业群教学质量诊断机制的优化路径

（一）构建智能化诊断平台

构建智能化诊断平台是高职院校智能智造专业群教学质量诊断机制优化的基础，其核心目标是通过技术手段实现教学数据的全面采集、精准分析与高效应用。首先，需要整合物联网、云计算、大数据等先进技术，搭建统一的诊断平台。物联网技术能够实时采集教学设备、实验仪器、学生行为等数据，为诊断提供丰富的数据源。大数据技术能够从海量数据中提取有价值的信息，为教学质量诊断提供科学依据。云计算技术为平台提供强大的计算与存储能力，支持大规模数据的处理与分析。为更清晰地展示智能化诊断平台的功能特点，表 1 详细对比了各模块的功能描述与技术特点。

通过表 1 可以看出，智能化诊断平台的各模块功能明确，技术特点突出，能够全面支持教学数据的采集、清洗、存储与分析，为教学质量诊断提供强有力的技术支撑。开发智能化诊断工具是平台建设的关键环节。学习效果评估系统能够对学生的学习行为与成果进行多维度分析，为个性化学习提供支持依据。课程质量评估系统能够对课程设计、资源利用等方面进行全面诊断，优化课程建设。这些工具的开发需要结合智能智造专业群的特点，确保其针对性与实用性。此外，平台的可扩展性与兼容性是确保其长期运行的重要保障。诊断平台需要支持与其他教学管理系统的无缝对接，实现数据的共享与互通。同时，平台应具备良好的可扩展性，能够根据教学需求的变化不断升级与优化。随着人工智能技术

表 1　智能化诊断平台功能对比

模块名称	功能描述	技术特点
数据采集模块	实时采集教学设备、学生行为数据	支持多种设备接入，高并发处理
数据清洗模块	清洗无效数据，确保数据质量	自动化清洗，支持自定义规则
数据存储模块	存储海量教学数据，支持快速检	分布式存储，高可用性
数据分析模块	分析教学行为、学习效果等数据	基于机器学习算法，高精度分析
数据行为监控	监控教师教学行为，提供改进建议	实时反馈，支持多维度分析
学习效果反馈	分析学生学习效果，提供优化路径	个性化报告，支持动态调整
课程优化建议	评估课程质量，提供优化方案	基于数据驱动，支持多场景应用
资源管理优化	优化教学资源配置，提高利用率	智能推荐，支持动态调整

的发展，平台引入智能推荐算法，为教师与学生提供更加精准的诊断结果与改进建议。在平台的实际应用中，还需要注重数据的安全性与隐私保护。教学数据涉及教师与学生的个人信息，必须采取严格的数据加密与访问控制措施，确保数据的安全存储与传输。同时，平台应遵循相关法律法规，明确数据的使用权限与范围，避免数据滥用。通过构建智能化诊断平台，高职院校智能智造专业群能够实现教学质量的全面监控与持续优化，为培养高素质技术技能人才提供有力支撑。

（二）完善诊断指标体系

完善诊断指标体系是确保高职院校智能智造专业群教学质量诊断科学性与全面性的关键。首先，诊断指标体系的设计需要紧密结合智能智造专业群的特点，涵盖“教师教学、学生学习、课程设计、资源管理”等多个维度。在教师教学方面，指标包括教学方法的创新性、教学内容的实用性、课堂互动的有效性等。在学生学习方面，指标包括学习目标的达成度、学习过程的参与度、学习成果的满意度等。在课程设计方面，指标包括课程目标的明确性、课程内容的系统性、课程资源的丰富性等。在资源管理方面，指标包括教学设备的利用率、实验资源的共享性、教学经费的合理性等。其次，明确各项指标的具体内涵与评估标准是确保诊断结果客观性与可操作性的关键。同时，指标体系的评估方法需要科学合理，采用定量与定性相结合的方式，如通过问卷调查、课堂观察、数据分析等多种手段获取评估数据，确保诊断结果的全面性与准确性。此外，诊断指标体系的动态更新是适应教学需求变化的重要保障。随着智能智造技术的快速发展，专业群的教学目标与内容也在不断调整，诊断指标体系需要定期更新，确保其与教学实践的动态匹配。在指标体系的实际应用中，还需要注重其可操作性与可推广性。指标体系的设计应尽量简洁明了，避免过于复杂或冗余，确保教师、学生及管理者能够轻松理解与使用。再通过收集教师、学生及管理者对指标体系的反馈意见，识别其存在的问题与改进空间，并根据反馈结果对指标体系进行优化与调整。例如，定期召开研讨会，邀请相关专家与用户代表共同讨论指标体系的改进方向与实施策略。

（三）强化诊断结果的应用

强化诊断结果的应用是提升高职院校智能智造专业群教学质量诊断机制实效性的核心。首先，将诊断结果作为教师教学改进的重要依据，为教师提供针对性的教学优化建议。例如，通过教学行为分析系统识别教师在课堂互动、教学方法等方面的问题，为其提供具体的改进策略与资源支持，帮助其提升教学效果。同时，学校组织教学研讨会或工作坊，邀请优秀教师分享教学经验，促进教师之间的交流与学习。其次，将诊断结果应用于学生学习支持，为学生提供个性化的学习资源与指导。例如，通过学习效果评估系统识别学生在知识掌握、技能应用等方面的不足，为其推荐适合的学习资源与学习路径，帮助其提升学习效果。再次，将诊断结果作为教学管理决策的重要参考，优化资源配置与政策制定。例如，通过课程质量评估系统识别课程设计中的问题，优化课程内容与教学方法，提升课程的整体质量。最后，学校根据诊断结果调整教学资源的分配，确保资源的高效利用。在诊断结果的实际应用中，还需要注重其可操作性与可推广性。诊断结果的分析与解读应尽量简洁明了，避免过于复杂或专业，确保教师、学生及管理者能够轻松理解与使用。

（四）推动个性化诊断与支持

推动个性化诊断与支持是满足高职院校智能智造专业群师生多样化需求的重要举措。通过大数据分析技术，为教师和学生提供精准的诊断结果，帮助其识别问题并制定改进策略。并对实际数据的个性化诊断结果进行统计，旨在展示教师和学生在不同维度的诊断结果分布情况。

根据统计结果可以得出，教师在“教学资源使用”

方面展现出了较高的水平，但在“教学方法”及“课堂管理能力”方面尚有提升空间。学生在“学习参与度”上表现积极，但在“技能应用”及“知识掌握深度”上仍有待加强。基于此，为教师和学生设计了一系列针对性的改进策略与支持措施。对于教师而言，首要任务是优化其教学方法并强化课堂管理技巧。将深入分析教师的教学行为数据，精准定位其在教学方法运用、课堂氛围营造及学生互动管理等方面的短板。随后，提供一系列定制化的改进建议，如引入互动式教学、情境模拟等先进教学方法，并配套相应的培训资源与案例分享，助力教师不断提升教学能力。同时，加强课堂管理技巧的培训，指导教师如何有效管理课堂秩序，激发学生的学习兴趣与参与度。针对学生方面，将重点关注其技能应用与知识体系的完善。通过细致分析学生的学习行为数据，明确学生在技能实践操作、理论知识内化等方面的薄弱环节。基于此，为每位学生量身定制学习路径，推荐适合的学习资源与课程，如在线实操教程、知识巩固练习等，以帮助学生有效提升技能应用水平与知识掌握程度。对于知识掌握得分较低的学生，将特别推荐基础强化课程，通过系统复习与巩固，帮助其打下基础。此外，学校将建立全面的学习支持中心，不仅提供“一对一”的学习辅导，还关注学生的心理健康，为其搭建心理支持平台，帮助学生解决学习过程中遇到的各种困难与挑战。

（五）建立反馈与闭环管理机制

建立反馈与闭环管理机制对高职智能智造专业群教学质量诊断至关重要。通过问卷、访谈收集教师、学生及管理者的反馈，识别问题并提出改进建议。设计问卷了解对诊断工具、指标体系、结果应用的满意度，为优化提供依据。定期评估实施效果并公开结果，增强参与积极性。根据反馈优化机制，形成闭环管理，定期召开研讨会讨论改进策略，明确责任分工与实施流程。在实际应用中，注重可操作性与可推广性，设计简洁的反馈方法，组织培训提升参与度。

（六）建立持续改进机制

建立持续改进机制是确保高职智能智造专业群教学质量诊断机制动态优化与长效运行的关键。首先，明确持续改进的目标与原则，如提升诊断机制的精准性、优化教学资源配置等，并遵循“数据驱动、全员参与、动态优化、闭环管理”的原则，确保改进机制的科学性与可持续性。其次，构建数据驱动的改进模型，通过大数据分析识别诊断机制中的问题与改进点，明确改进方向、策略与实施步骤。最后，实施诊断机制的动态优化，根据改进模型的结果优化诊断工具的功能与性能，提升诊断的精准性与效率。简化诊断流程，减少冗余环节，提高诊断机制的可操作性与用户体验。在持续改进机制的实际应用中，还需要注重其可操作性与可推广性。改进措施的设计应尽量简洁明了，避免过于复杂，确保相关方能够轻松理解与使用。

四、结束语

在数智时代的推动下，高职院校智能智造专业群的教学质量诊断机制迎来了优化与创新的重要契机。本文基于数智时代背景，提出高职院校智能智造专业群建设中教学质量诊断机制的优化路径。该路径的实施将有助于提升教学质量诊断的科学性与有效性，为高职院校智能智造专业群的高质量发展提供坚实保障。未来，随着技术的不断进步与教育模式的持续创新，教学质量诊断机制将进一步向智能化、精准化方向发展。高职院校应积极拥抱数智时代的变革，持续优化诊断机制，为培养高素质智能制造人才、服务区域经济发展作出更大贡献。

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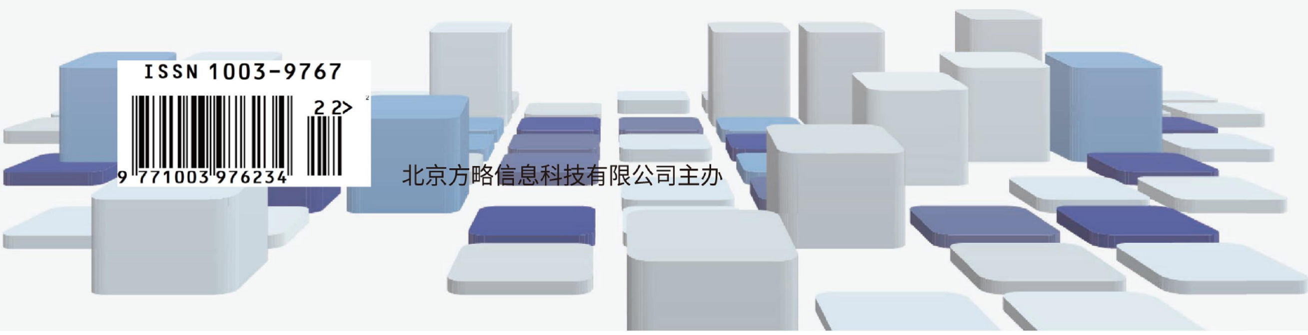

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计算机工程应用技术

算法语言

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基于 AI 技术的高校计算机类课程教学方法研究

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摘　要：传统高校计算机类课程教学方法中，虚拟现实（Virtual Reality，VR）教学空间场景未对学生交互行为进行跟踪，造成教学方法响应时间较长，为此分析人工智能（Artificial Intelligence，AI）技术在高校计算机类课程教学中的应用。使用 3D Max 软件创建 VR 教学空间场景，将场景文件发送给学生后，对学生交互行为进行跟踪。引入 AI 技术获取通信信号，实现 AI 技术在高校计算机类课程教学中的应用。实验结果表明，该研究方法响应时间更短，更适用于高校计算机类课程教学。

关键词：人工智能（AI）技术；高校计算机课程；虚拟现实（VR）

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The Application of AI Technology in the Teaching of Computer Courses in Colleges and Universities

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Abstract: In the traditional teaching methods of computer courses in colleges and universities, the interactive behavior of students is not tracked in the Virtual Reality (VR) teaching space scene, which leads to the long response time of traditional methods. Based on this, the application of Artificial Intelligence (AI) technology in the teaching of computer courses in colleges and universities is put forward. Use 3D Max software to create VR teaching space scenes, send scene files to students, track students' interactive behaviors, introduce AI technology, and obtain communication signals to realize the application of AI technology in the teaching of computer courses in colleges and universities. The comparative experimental results show that this research method has faster response time and is more suitable for the teaching of computer courses in colleges and universities.

Keywords: Artificial Intelligence (AI) technology; computer courses in universities; virtual reality

0　引言

随着科技的不断发展，人工智能（Artificial Intelligence，AI）逐渐渗入各行各业，改变了人们的生活和工作方式[1]。在教育领域，AI 技术的应用为教学方法的改革和创新提供了新的机遇[2]。特别是在高校计算机类课程的教学中，AI 技术的引入不仅可以提高教学效率，还可以帮助学生更好地理解和掌握复杂的技术知识[3]。

周凯等在“互联网 +”背景下对混合教学模式在高校计算机类课程中的应用情况进行了研究，该模式将线上与线下学习有机结合起来，有利于提高学生自主学习

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能力和创新能力[4]。王西锋提出了计算机类专业基础课程实践教学改革方法，通过分析计算机专业基础课程的特点和实验环节中存在的问题，结合应用型人才培养的目标，从实验内容设置、教学方法、考核方式等方面进行探索和改革[5]。但这些方法存在使用场景受限的问题。对此，提出基于 AI 技术的高校计算机类课程教学方法，以期为提升教学质量和培养优秀计算机人才提供参考。

1 AI 技术在高校计算机类课程教学中的应用设计

1.1 建立 VR 教学空间场景

为使虚拟学习环境与实际场景相协调，使用 3D Max 软件创建虚拟现实（Virtual Reality，VR）教学空间场景。结合高校计算机远程学习方法的实际需求，调整设计虚拟学习环境参数，获得更高分辨率的虚拟场景，提高学习方法的性能。在之前的教育场景建模过程中，Rhino 软件可以用于创建交互式对象，如对象教育场景。Rhino 软件可以采用多条 NURBS 曲线组成交互对象，这些 NURBS 曲线可组成场景曲面图，其表达式为

$$M\left(a,b\right)=\frac{\sum w_{ij}d_{ij}B_{i,k}\left(a\right)B_{j,I}\left(b\right)}{\sum w_{ij}B_{i,k}\left(a\right)B_{j,I}\left(b\right)} \tag{1}$$

式中：$M(a,b)$ 为 NURBS 曲线点的空间坐标；$B_{j,I}$ 为 NURBS 曲线 b 的控制函数；d_{ij} 为相关曲线的垂直控制；w_{ij} 为曲线的控制权重；$B_{i,k}$ 为 k 线规范中样条曲线 b 的主要函数。首先，根据交互对象的真实信息改变交互对象的设计表面，引入外部映射数据，创建交互对象的 VR 场景。其次，将 Rhino 软件生成的交互式客体导入 3D Max。最后，设置鼠标启动参数。因此，虚拟教学环境像素的计算公式为

$$\begin{cases}S_x=B_{i,k}L_x\cos\alpha\cdot tNs_z\\S_y=B_{i,k}L_y\cos\alpha\cdot tNs_z\end{cases} \tag{2}$$

式中：S_x、S_y 分别为虚拟教学环境的水平像素和垂直像素；s_z 为虚拟教学环境的总像素；L_x、L_y 分别为虚拟教学环境中几何体的水平长度和垂直长度；α 为实际场景角度参数；t 为实际场景光时间参数；N 为虚拟场景中的一个几何曲面数。使用式（2）开发高分辨率虚拟学习环境后，学生可以在虚拟环境中学习计算机课程，从而提高他们的学习兴趣。

1.2 学生交互行为跟踪

为确定学生是否在建立的 VR 教学空间中与物体发生接触，采取碰撞检测算法检测是否出现人机交互。对轴协调阈值包围的表达式为

$$O=\{S_y(x_r,y_r,z_r)|x_{\min}\leqslant x_r\leqslant x_{\max},y_{\min}\leqslant y_r\leqslant y_{\max},\ z_{\min}\leqslant z_r\leqslant z_{\max}\} \tag{3}$$

式中：(x_r,y_r,z_r) 为虚拟学习环境中几何框的空间坐标值；$x_{\min}$、$y_{\min}$、$z_{\min}$ 分别为几何框的最小空间坐标值；$x_{\max}$、$y_{\max}$ 和 $z_{\max}$ 分别为几何框的最大空间坐标值。使用式（3）检测学生与几何虚拟学习环境之间的冲突，步骤如下：首先，确定矩形立方体虚拟学习环境周围的几何空间坐标；其次，确定每个坐标轴的几何中心投影列表；最后，在分离结果的基础上，学生的协调性与协调性的极限值相一致，实现最实用的人机交互训练。

随着用户在真实空间中的活动，外部交互设备（如 Kinect）应在不同场所之间建立协调的转换关系，使用协调坐标 (x_r,y_r,z_r) 作为真实教育的协调坐标，使用协调坐标 (x_n,y_n,z_n) 作为真实世界的用户协调坐标。两坐标系之间的动态输入速度为

$$\begin{pmatrix}x_r\\y_r\\z_r\end{pmatrix}=\begin{pmatrix}\boldsymbol{R}&t\\0^T&1\end{pmatrix}\begin{pmatrix}x_n\\y_n\\z_n\\1\end{pmatrix}=B\begin{pmatrix}x_n\\y_n\\z_n\\1\end{pmatrix} \tag{4}$$

式中：$\boldsymbol{R}$ 为反映用户协调坐标系相对于训练区域的协调坐标系的变换变量的 3×3 矩阵；T 为用户协调系统相对空间坐标系统的平移分量。根据式（4），从真实学习空间改变为用户坐标并跟踪用户坐标。Kinect 的外部摄像头将用户在训练室的行为更改为二维图像，并将模型放置在虚拟场景中，以恢复三维图像的建模。相机图像协调系统与用户协调系统的转换关系为

$$z_r\begin{pmatrix}x\\y\\1\end{pmatrix}=\begin{pmatrix}f&0&0&0\\0&f&0&0\\0&0&1&0\end{pmatrix}\begin{pmatrix}x_r\\y_r\\z_r\\1\end{pmatrix} \tag{5}$$

点 z 在二维图像上的投影为 $(0\quad f)$；f 为摄像头的焦距。由相似比例关系可得出

$$\begin{cases}x=\dfrac{x_rf}{z_r}\\y=\dfrac{y_rf}{z_r}\end{cases} \tag{6}$$

教学过程中，为确保学生的视觉效果更加真实，首先打开并跟踪学生瞳孔的变化，确定图像采集速度及图像的标度，确定从 0 ~ 160 的速度标值。其次，开闭运算处理后，通过巡逻瞳孔图像来揭示瞳孔的侧面变化，使用该设备获得瞳孔运动轨迹。

1.3 基于 AI 技术实现教学内容联动展示

为实现教学内容联动展示，引入 AI 技术，通过跟踪学生在虚拟学习环境中与物体发生接触的交互行为，制作通信信号，使用传输设备发送通信过程中产生的信号。AI 显示界面中，离散点空间距离的计算公式为

$$L=(t-t_0)v \tag{7}$$

式中：L 为 AI 显示器中 d 距离处的空间范围；t 为信号的发送时间；t_0 为信号的接收时间；v 为 AI 区域中

的发送速度。独立信号在接口上不可用，在 AI 接口内建立音频提取信号和图像提取信号之间的连接表达式为

$$w(x,y)=(2u_x u_y+G)/(u_x^2+u_y^2+G) \quad (8)$$

式中：w 为音频连接模型；u_x 为图像的线行帧；u_y 为位置的列；G 为识别因子。为避免展示过程中的视觉颜色差异，应构建 AI 界面的颜色差匹配，用公式表示为

$$M=\sum\left(x-x^{`}\right)^{T} K_{(rp)} \quad (9)$$

式中：M 为色差的分割阈值；K 为相应的色差率；x 为初始颜色识别率；$x^{`}$为界面角；r 为相应的颜色识别率；p 为颜色因子。基于 AI 技术实现教学内容联动展示，可为教师提供远程教育，以便学生在家中或其他远离教室的地方学习。当教师使用这种方法创建课程时，可实时采集教学图像、语音和其他相关教学数据，并将教学数据发送到服务器进行存储，再通过虚拟平台展示给学生。为保证虚拟展示质量，需准确地收集教学数据。教学内容联动展示流程如图 1 所示。

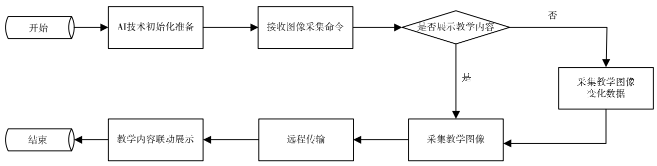

图 1　教学内容联动展示流程

由图 1 可知，教师使用 AI 技术实现教学内容联动展示时，应进行 AI 技术初始化准备，采集学习方法发出图像采集命令。开始远程授课，此时教学系统会自动捕捉教学图像，AI 将自动接收学习的图像。每次拍摄屏幕时，背景自动压缩图像，并将远程图像编码到压缩图像服务器进行进一步处理，实现了基于 AI 技术的教学内容联动展示。

2　实验论证

2.1　实验准备

以某地区的一所大型高校为例，设计一个对比实验。利用 Tomat/Apache 网络服务器、Java/C++/Meyeclpse 作为方法开发工具以及 Windows10 操作系统和 SQLServer2008 数据库为应用，创建高校培训终端测试环境。用于试点设计的设备的相关参数如表 1 所示。

将基于 AI 技术的教学方法分别与文献 [4] 方法和文献 [5] 方法进行对比分析。随机选取 30 份加载课程资源，采用 3 种方法对加载课程资源响应时间进行测试。

2.2　实验指标

实验以响应时间为验证指标进行对比验证。响应时间的计算公式为

$$t'=t_2-t_1 \quad (10)$$

式中：t' 为响应时间，s；t_1 为教师发起请求的时间；t_2 为系统返回结果的时间。

表 1　搭建测试环境的设备参数

设备		参数
服务器	Web 服务端	Inter PentiumG3250，内存 4GB，CPU 主频 3.2GHz
	数据库服务器	Inter PentiumG3250，内存 8GB，CPU 主频 2.9GHz
	通信	宽带 8MHz
客户端	PC	Inter PentiumG3250，内存 8GB，CPU 主频 3.2GHz
	通信	4MHz

2.3　实验结果分析

响应时间对比结果如表 2 所示。

表 2　三种方法响应时间对比结果

加载课程资源数量 / 份	本方法响应时间 /s	文献 [4] 方法响应时间 /s	文献 [5] 方法响应时间 /s
10	0.01	0.52	0.41
20	0.04	0.51	0.40
30	0.02	0.55	0.42

由表 2 可知，采用文献 [4] 方法时，其响应时间随着加载课程资源数量的增加而逐渐增加，平均约为 0.53 s；采用文献 [5] 方法时，平均响应时间约为 0.41 s；采用本方法时，响应时间约为 0.02 s，相比文献 [4] 方法、文献 [5] 方法分别减少了 0.51 s、0.39 s，且整体响应时间较短，具有一定的优势。

3　结语

为确保教学方法的有效性，提出基于 AI 技术在高校计算机类课程教学方法。该方法的测试结果表明，采用文章方法可有效提高教学效果，缩短响应时间。

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